Simulation Study for the 2nd HCal Prototype

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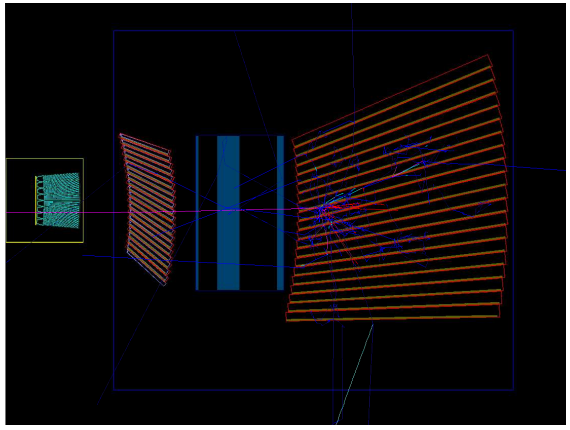
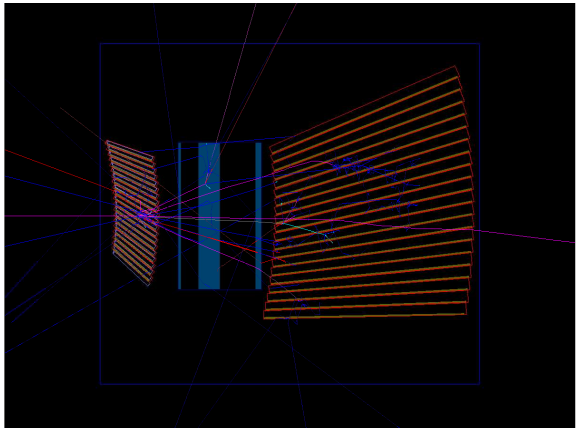
Outline

- Simulation framework
- Results for cosmic ray study
- Calorimeter performance from simulation
- Shower energy distribution study
  - Energy asymmetry variable
  - Can it be used for particle identification?

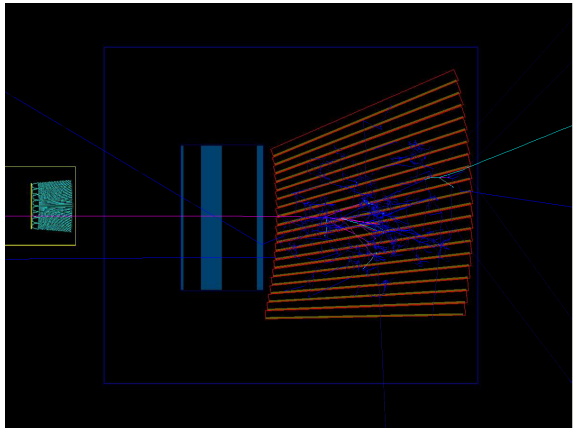
EMCal + Inner + Outer



Inner + Outer

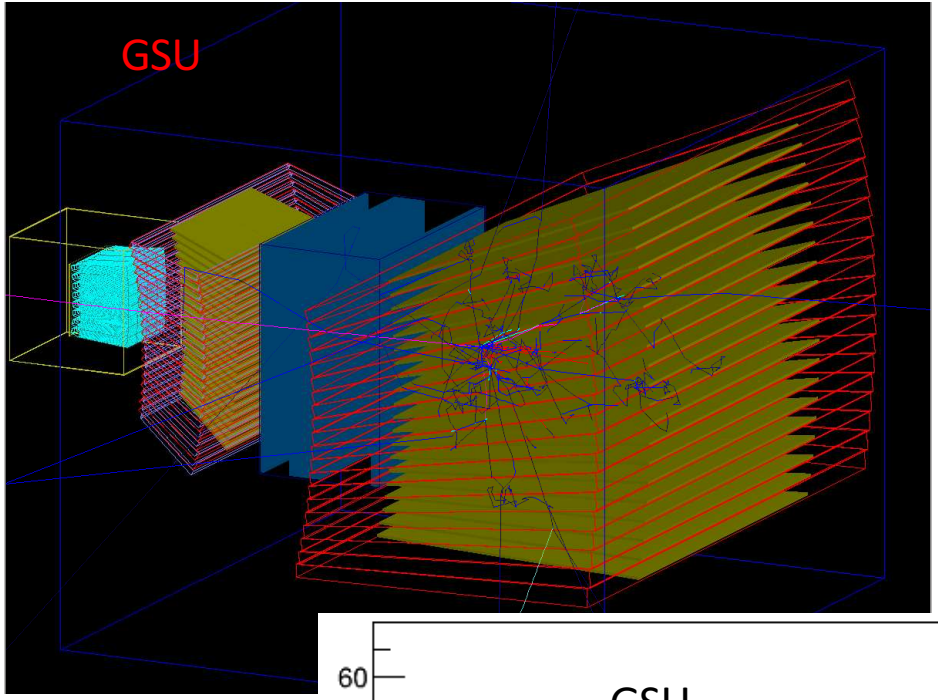


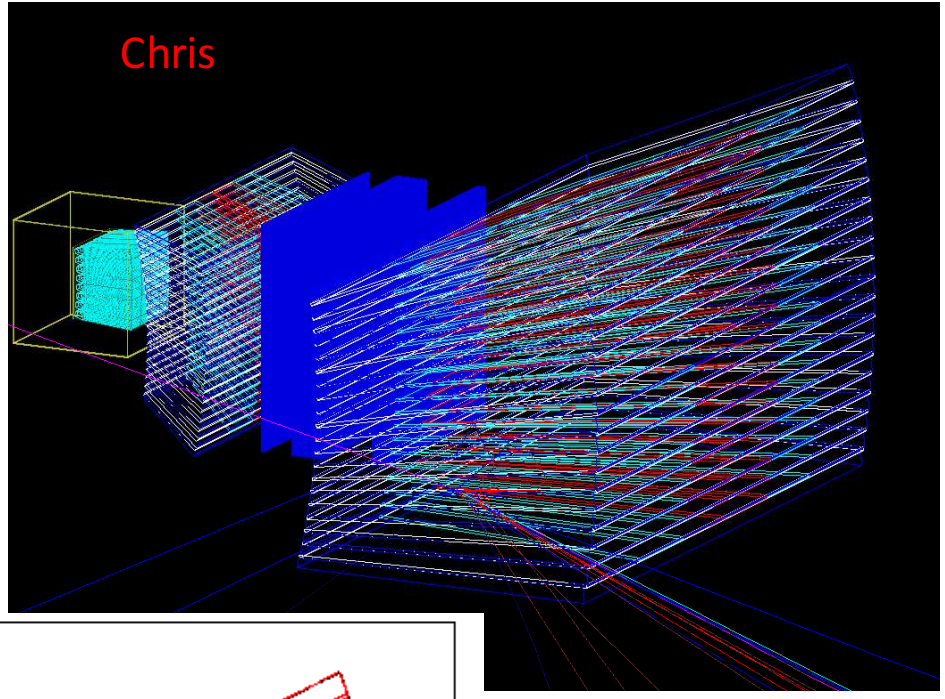
EMCal + Outer

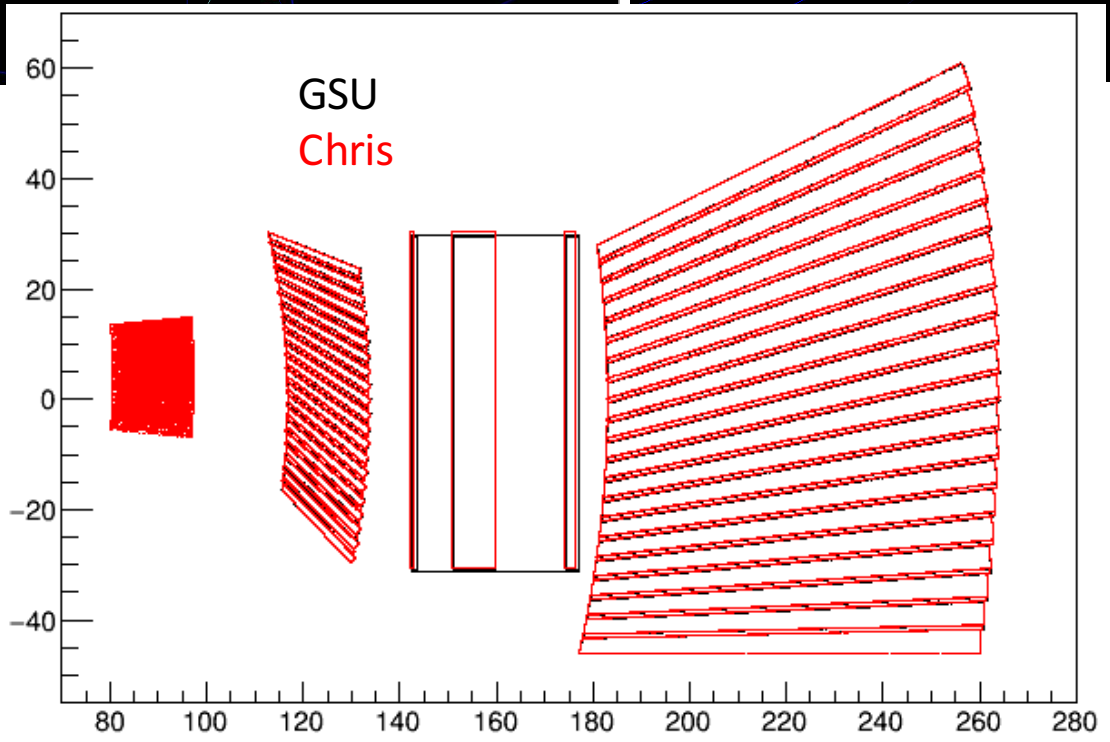


The first of the first

- Thanks go to Chris and Jin for taking care of the simulation framework which enables this simulation study.
- Rumor says that there are two versions of the HCal prototype simulation. One is GSU version and the other is Chris's version. It is actually true! As far as one can tell, they are very much identical (see the visual comparison in the next slide).
- The results presented here are from running GSU version of the geometry implementation for a few good reasons. One of these reasons is that there is existing software (that Liang has developed for the 1st prototype analysis) one can use to get the results relatively quickly with minimal changes.
- According to Murad, said on 7/2/2026, he "will start using Chris's geometry in whatever work … from now on".







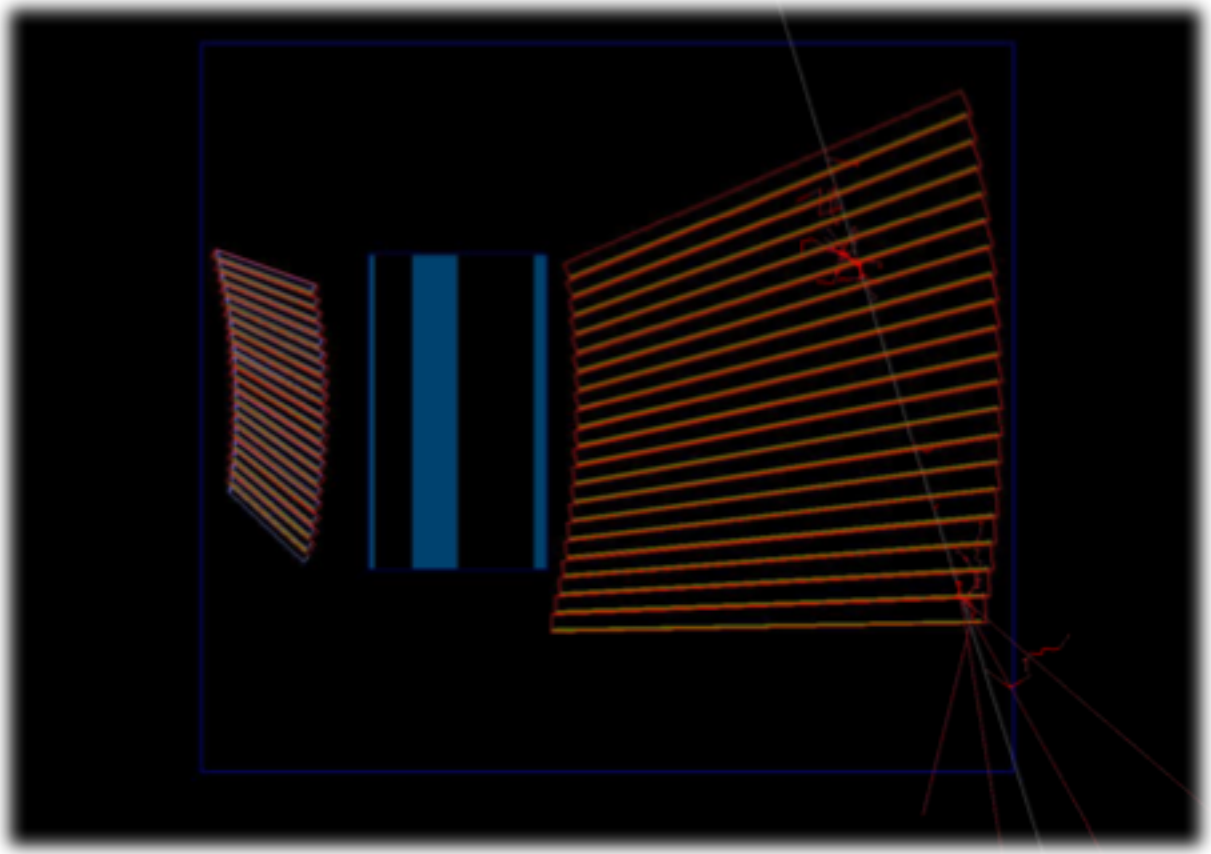
Geantino Test
Chris's Geom (red) superimposed on GSU's geom

Performance with Cosmic Rays

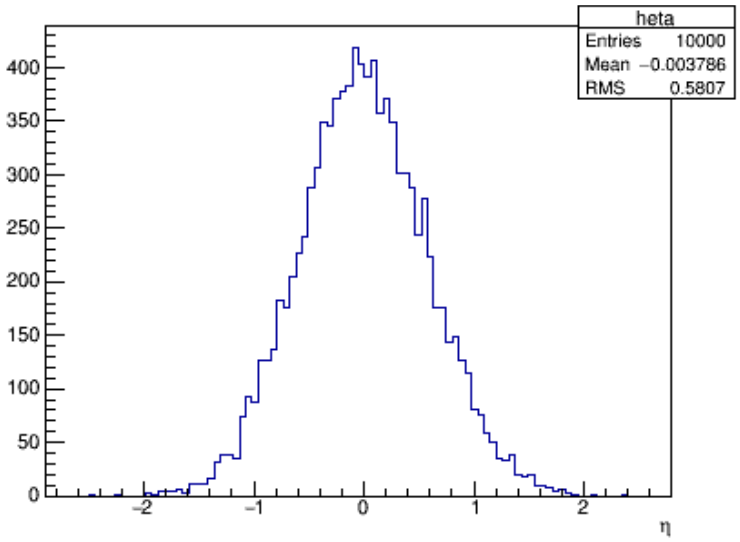
Start with a simpler problem

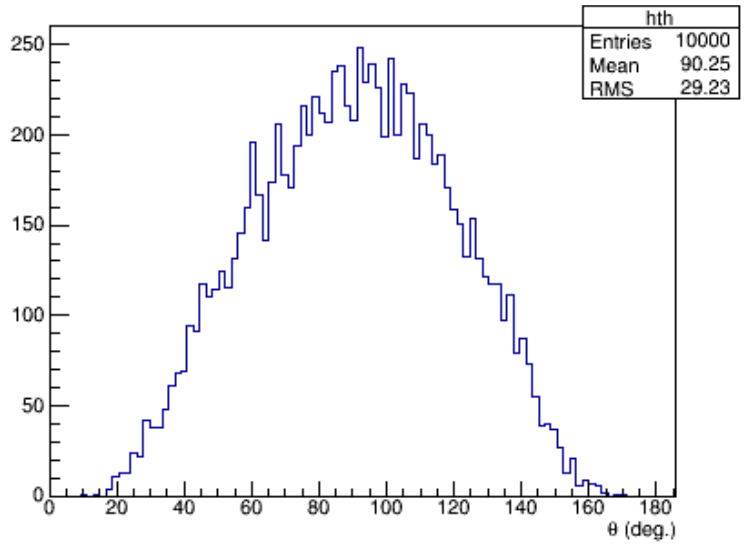
Cosmic Event Generator

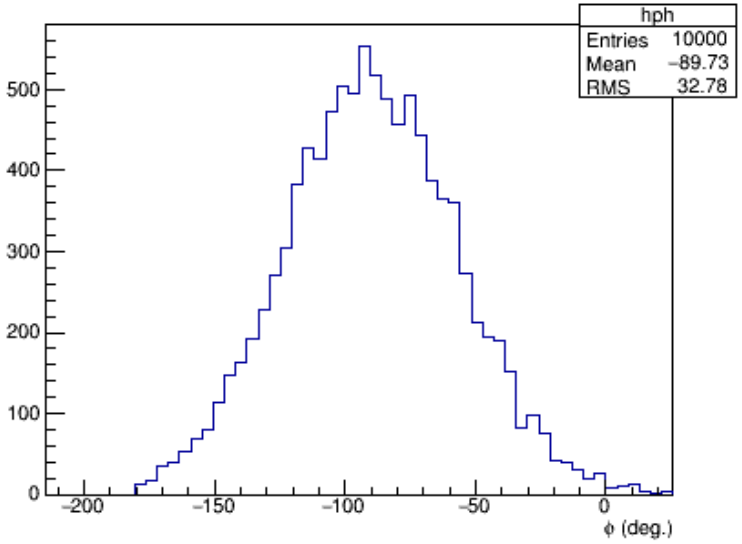
- Flat distribution of 4 GeV/c μ's at y=100 cm (μ^+/μ^- ~ 1.3)
- Flat y&z distributions that cover the inner and outer HCal only.
- σ=33° divergence in η & φ (approx. by Gaussian)
- 12.5% Momentum smearing (4.0 ± 0.5)

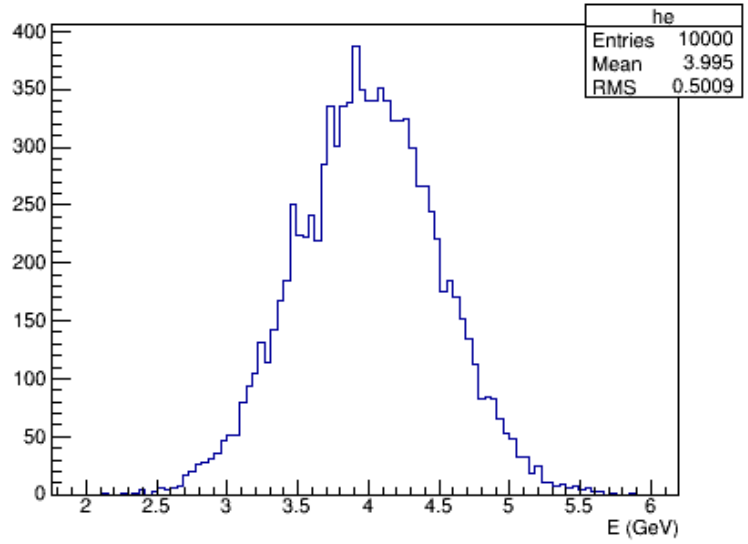


Cosmic Muon Distributions

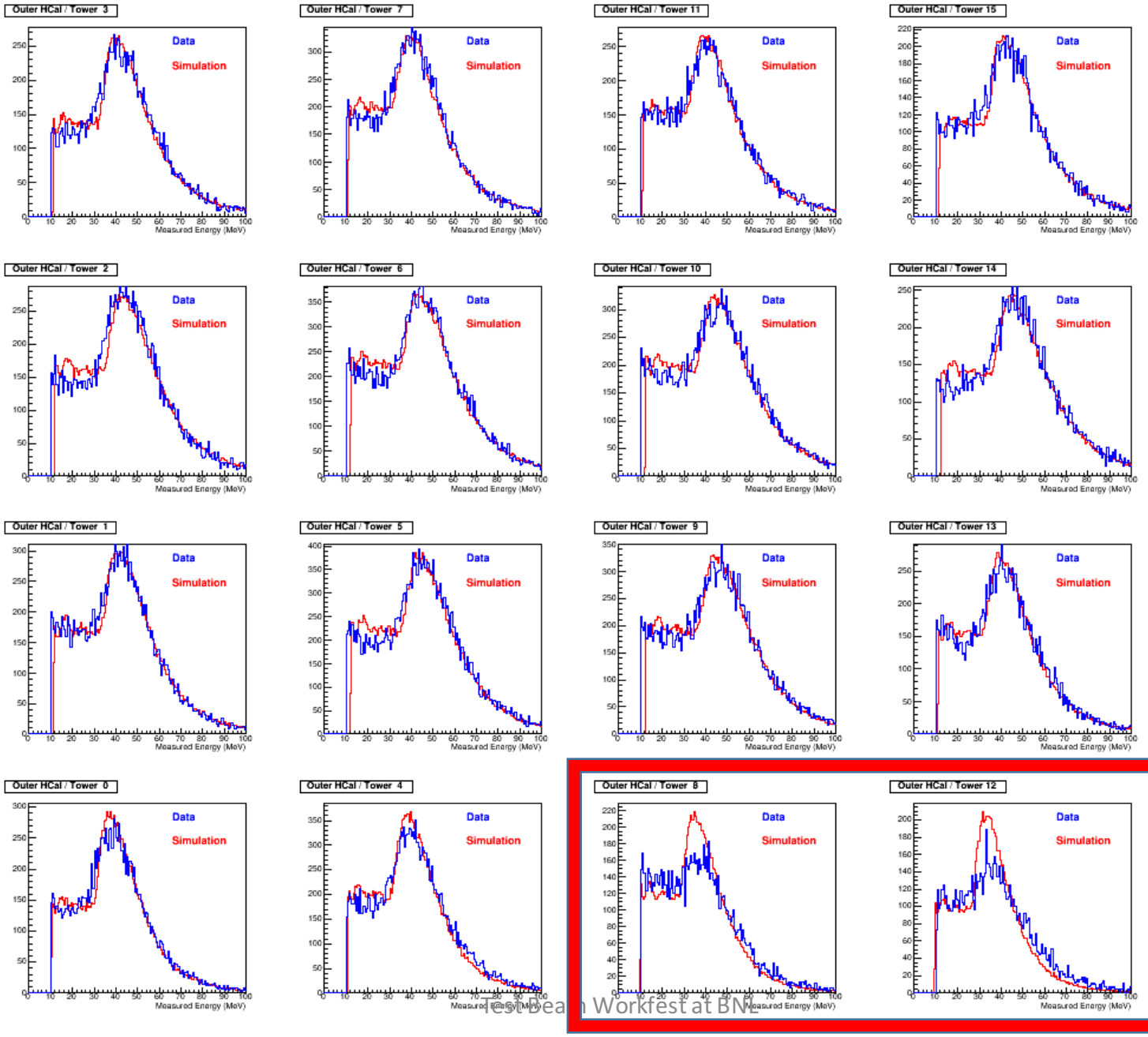








Outer HCal Tower Energy : Data vs Simulation



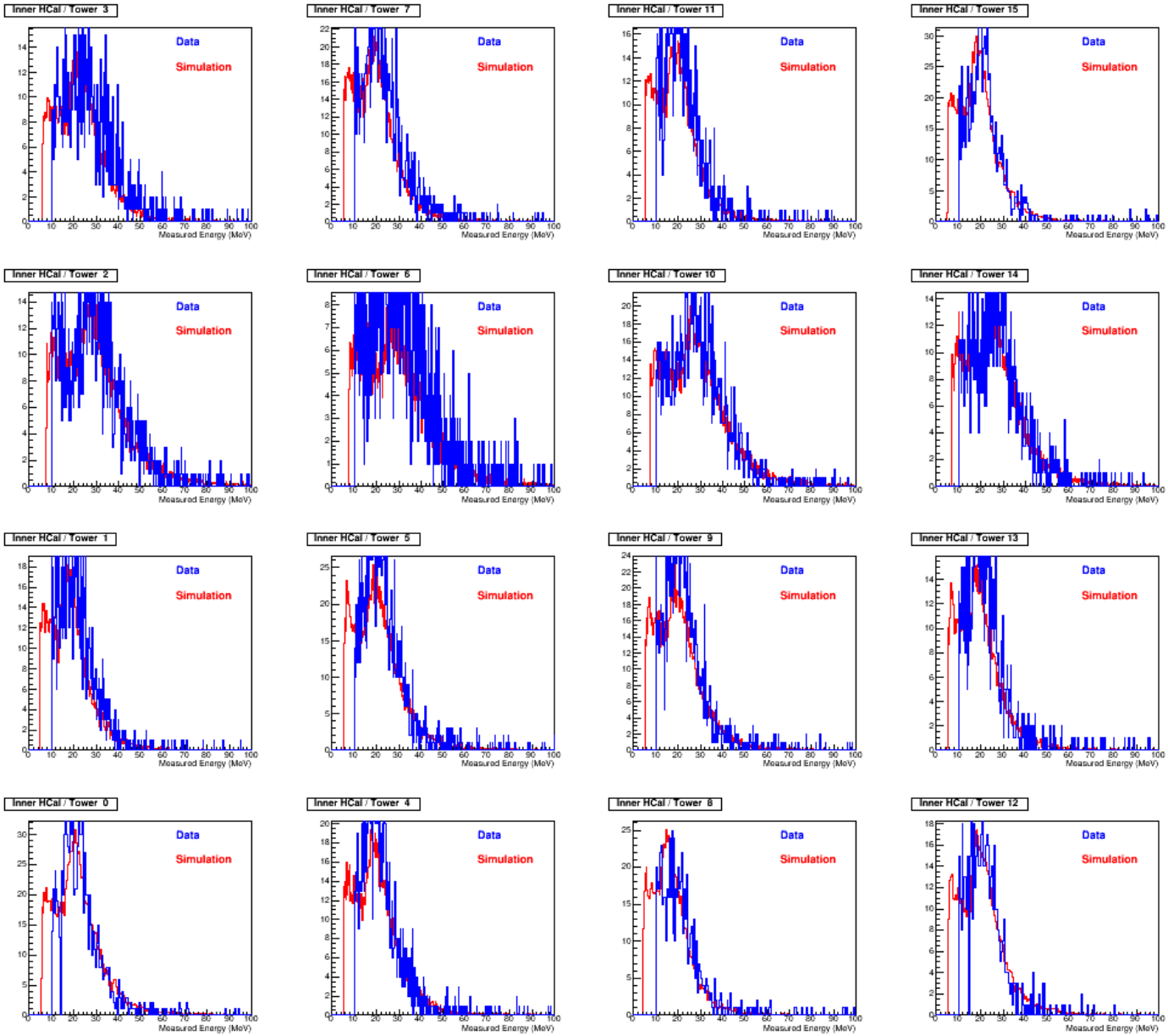
Data (run2026)

Simulation

Normalized by Integration from threshold to Max

Any known Issues?

Inner HCal Tower Energy: Data vs Simulation



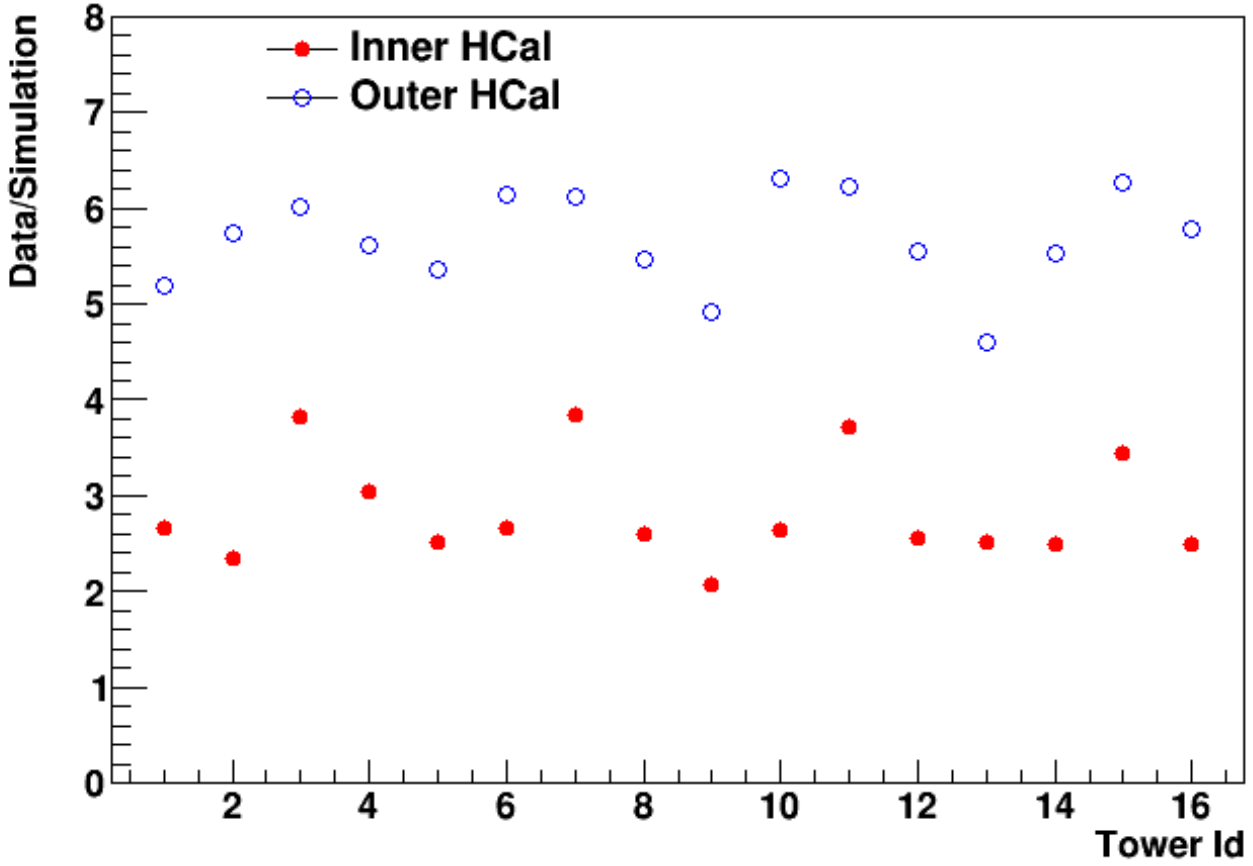
Data
(run2026)

Simulation

Normalized by Integration from threshold to Max

Statistics Is lower than the number of counts from outer Hcal !!! Not a bad match.

Tower by Tower Comparison



Are the variations caused by the gain variation? Could these be used as the ADC/Energy scale factor?

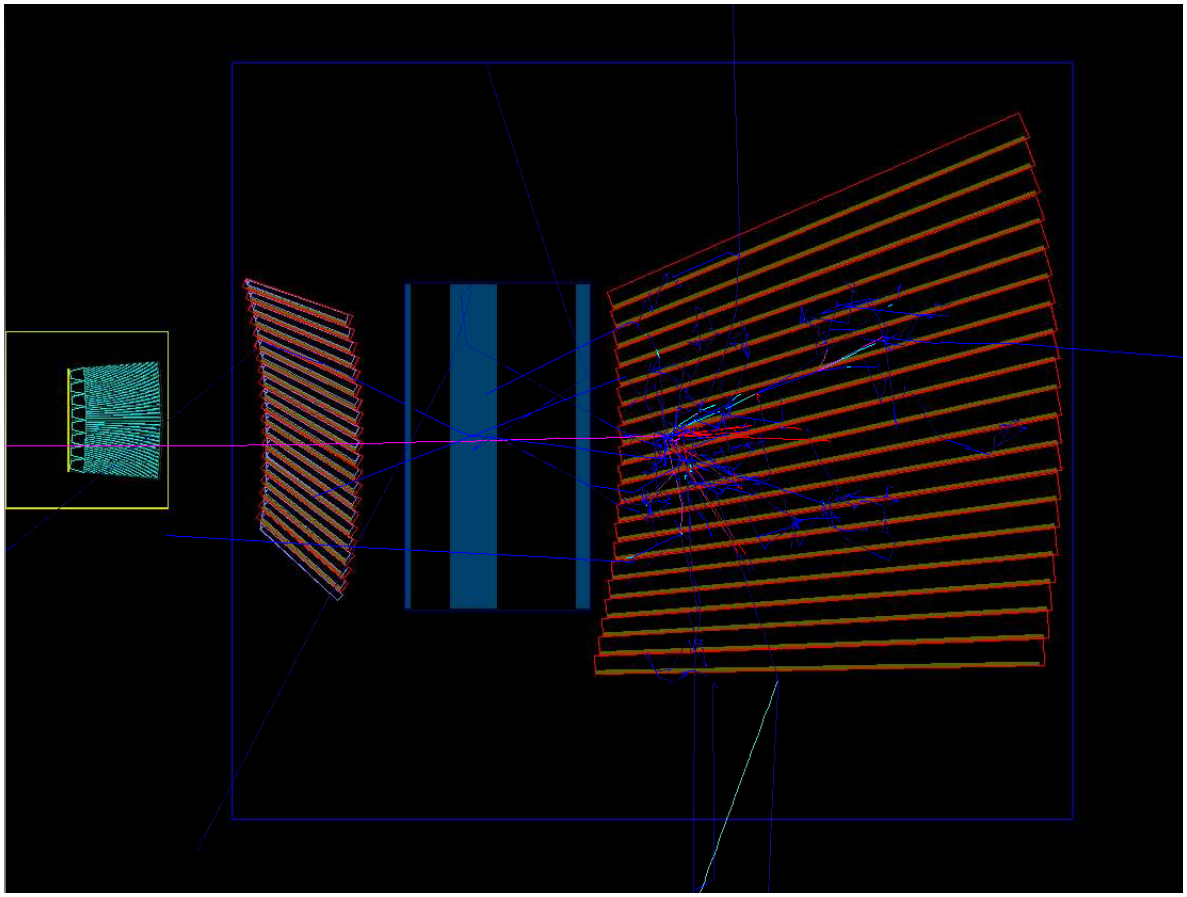
Results from the simulation study for the beam test configuration

No direct comparison with the results from the beam test yet.
More coordinated effort on this part should be done SOON.

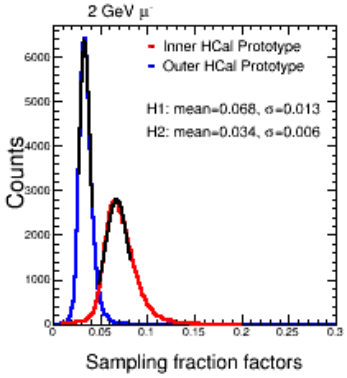
Test Beam Event Generator

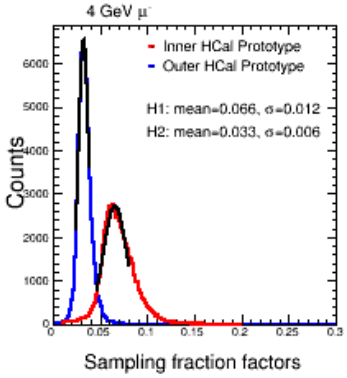
- (0,0,0) vertex distribution with 3x3 mm beam spot (0,0.7,0.7) (Gaussian)
- Run π^-, μ^- and e^- at 2, 4, 8, 16, 20, 24, 32, 40, 50 and 50 GeV
- 1 mrad angular divergence in η and φ / (-0.001 to 0.001) range.
- 2% momentum smearing
- Use μ for HCal SF and e for EMCal SF. (EMCal + Inner HCal + Outer HCal)

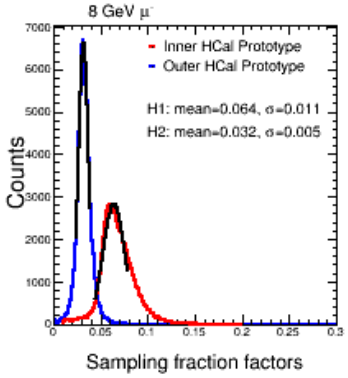
10 GeV π^-

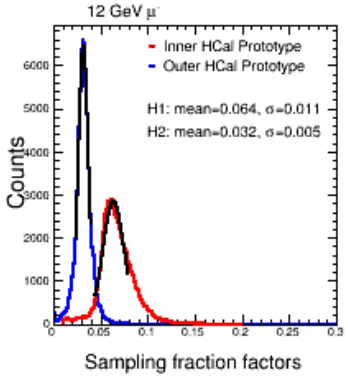


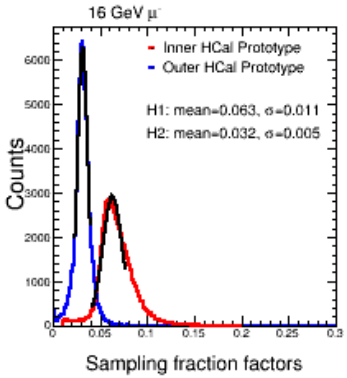
HCal Sampling Fraction Distributions / μ^-

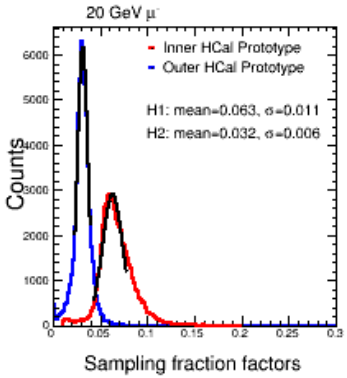


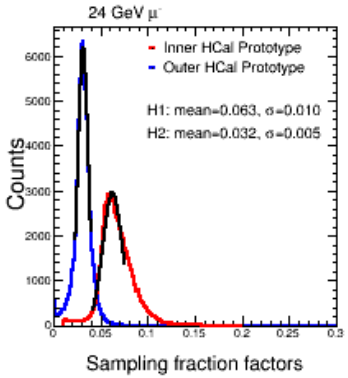


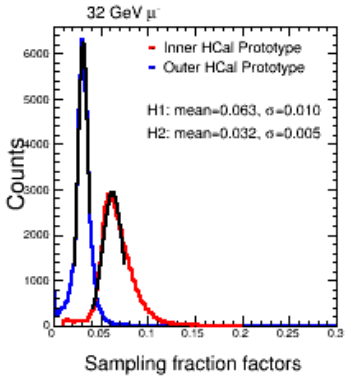


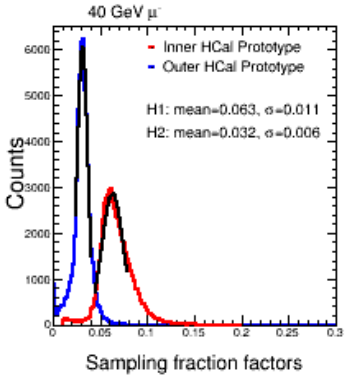


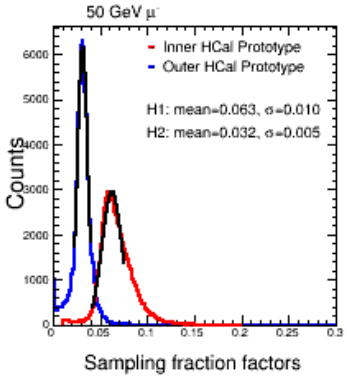


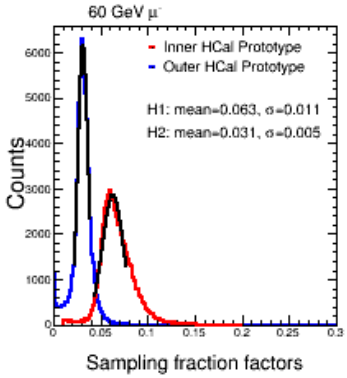








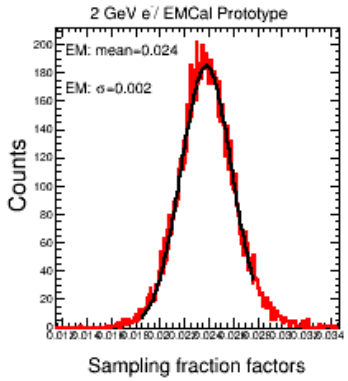


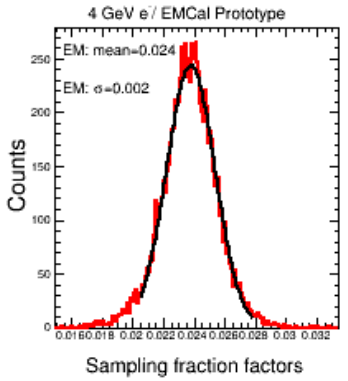


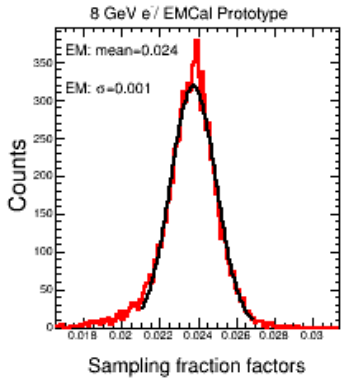
<Inner = 6.37%>

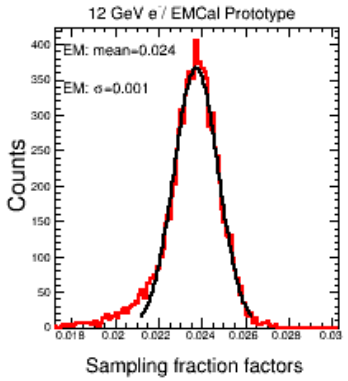
<Outer = 3.19%>

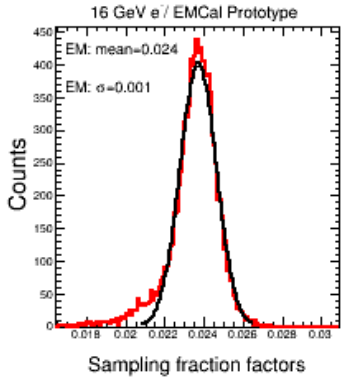
EMCal Sampling Fraction Distributions / e-

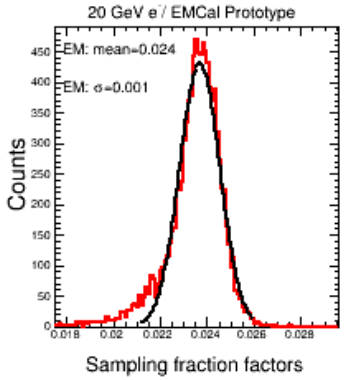


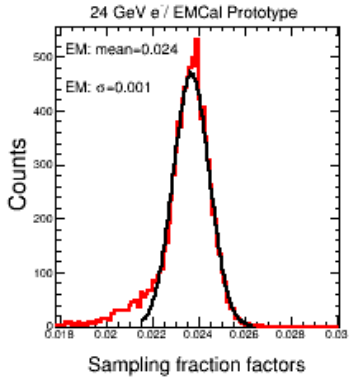


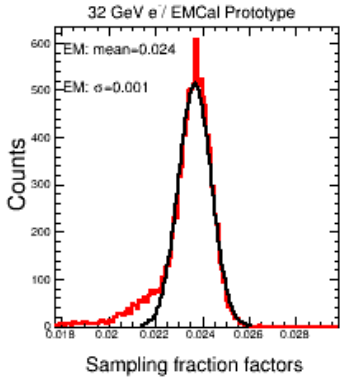


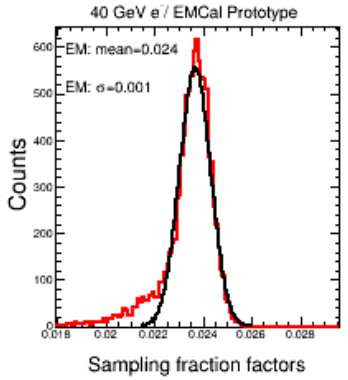


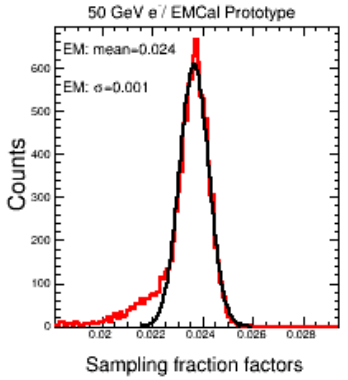


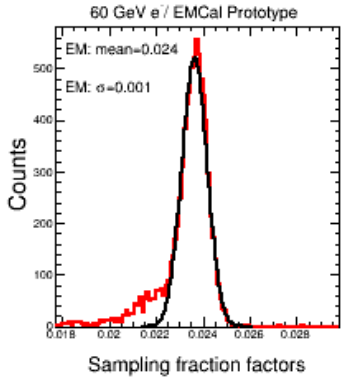






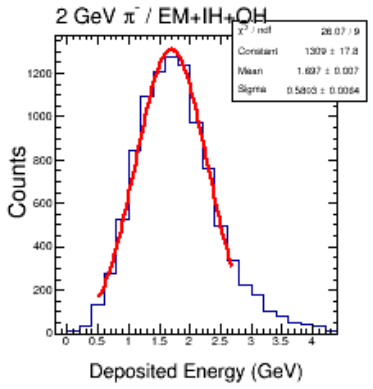


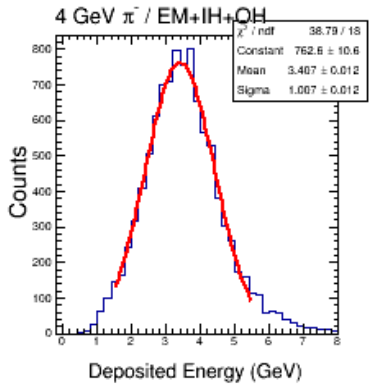


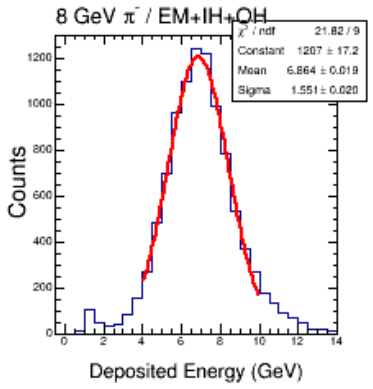


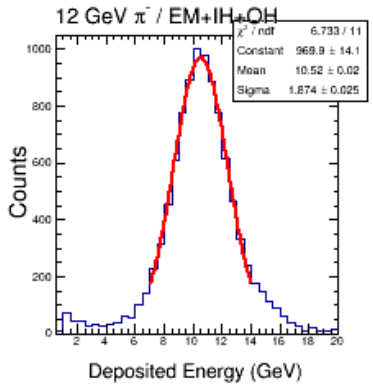
<EMCal = 2.37%>

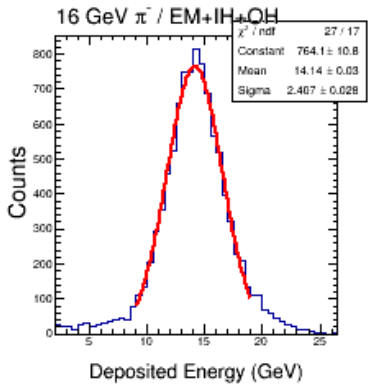
Reconstructed Energy / π^-

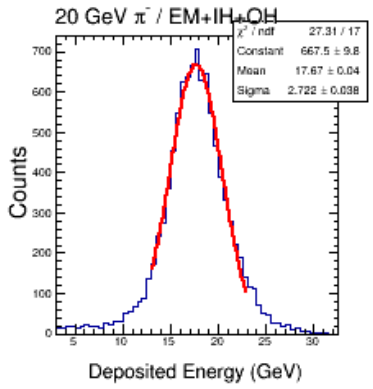


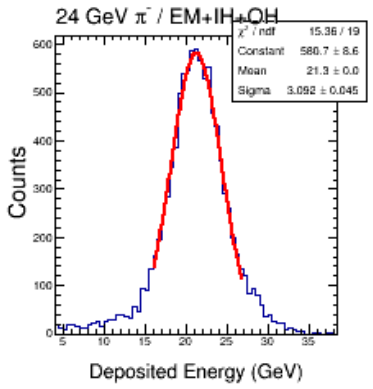


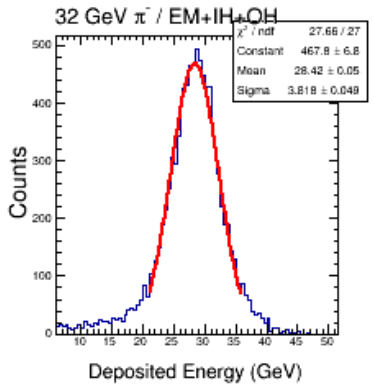


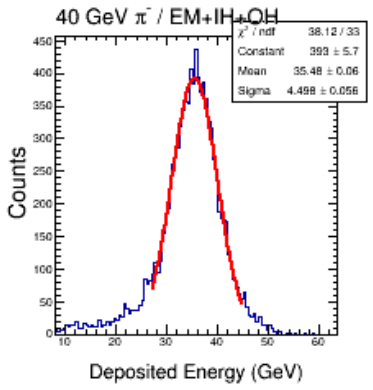


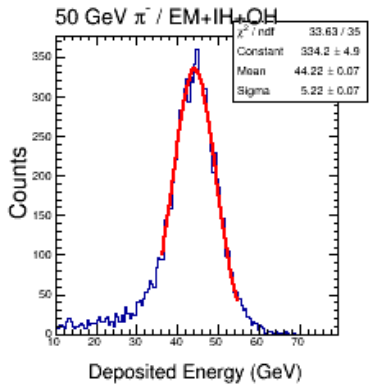


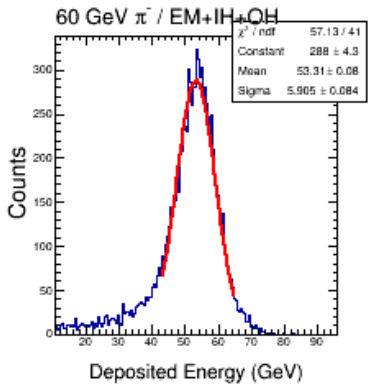




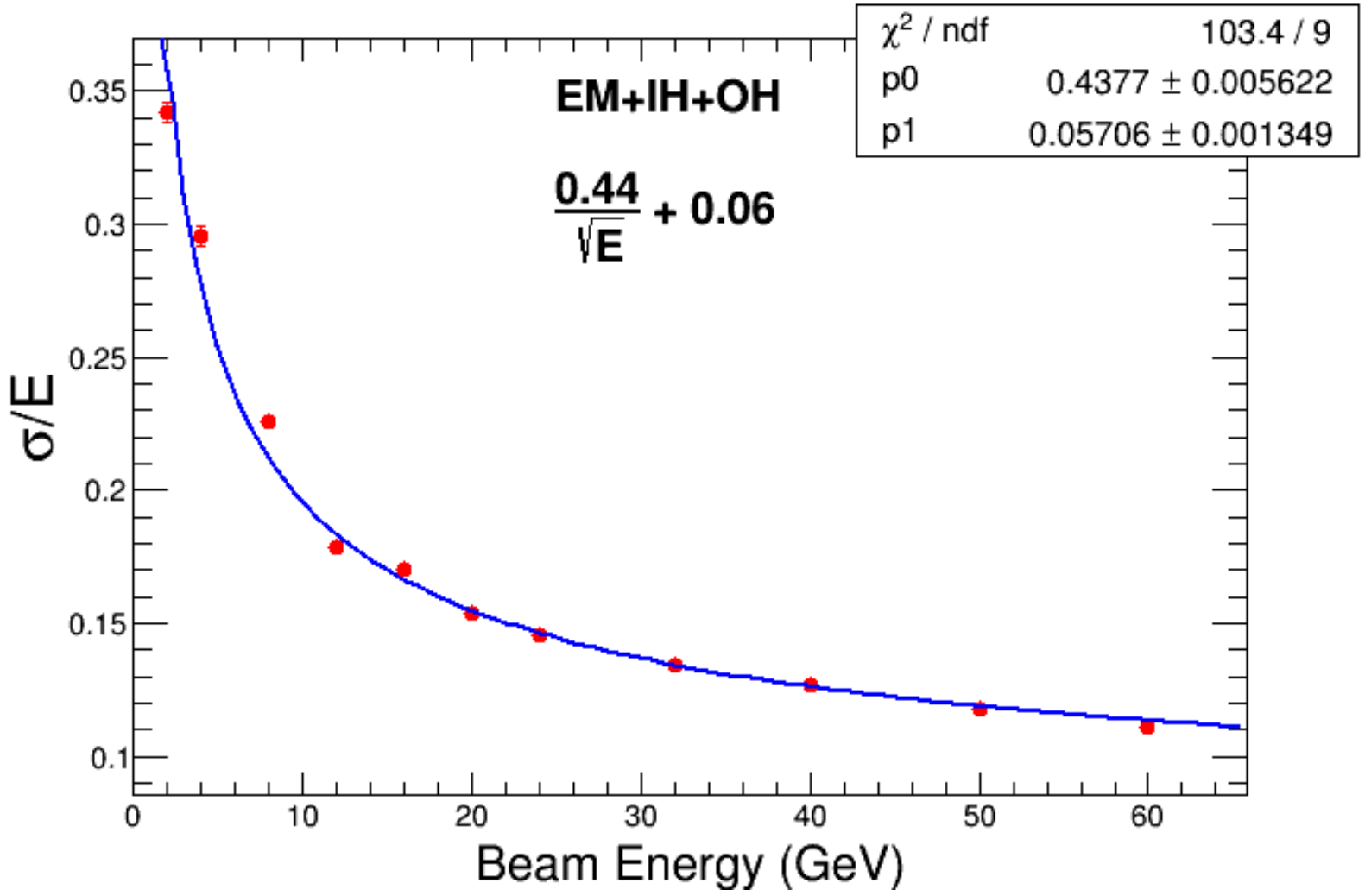




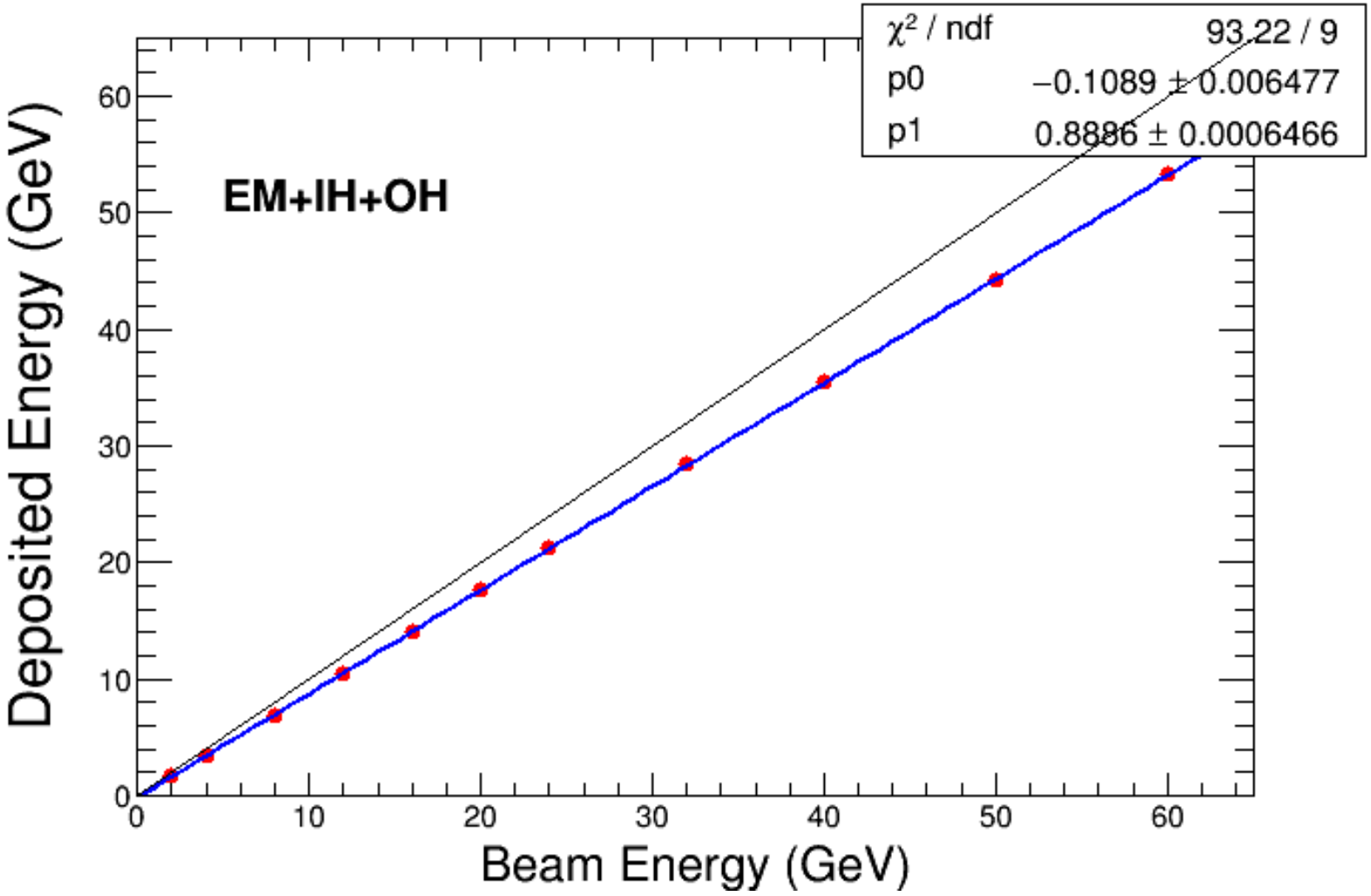




Energy Resolution (EMCal + Inner + Outer)

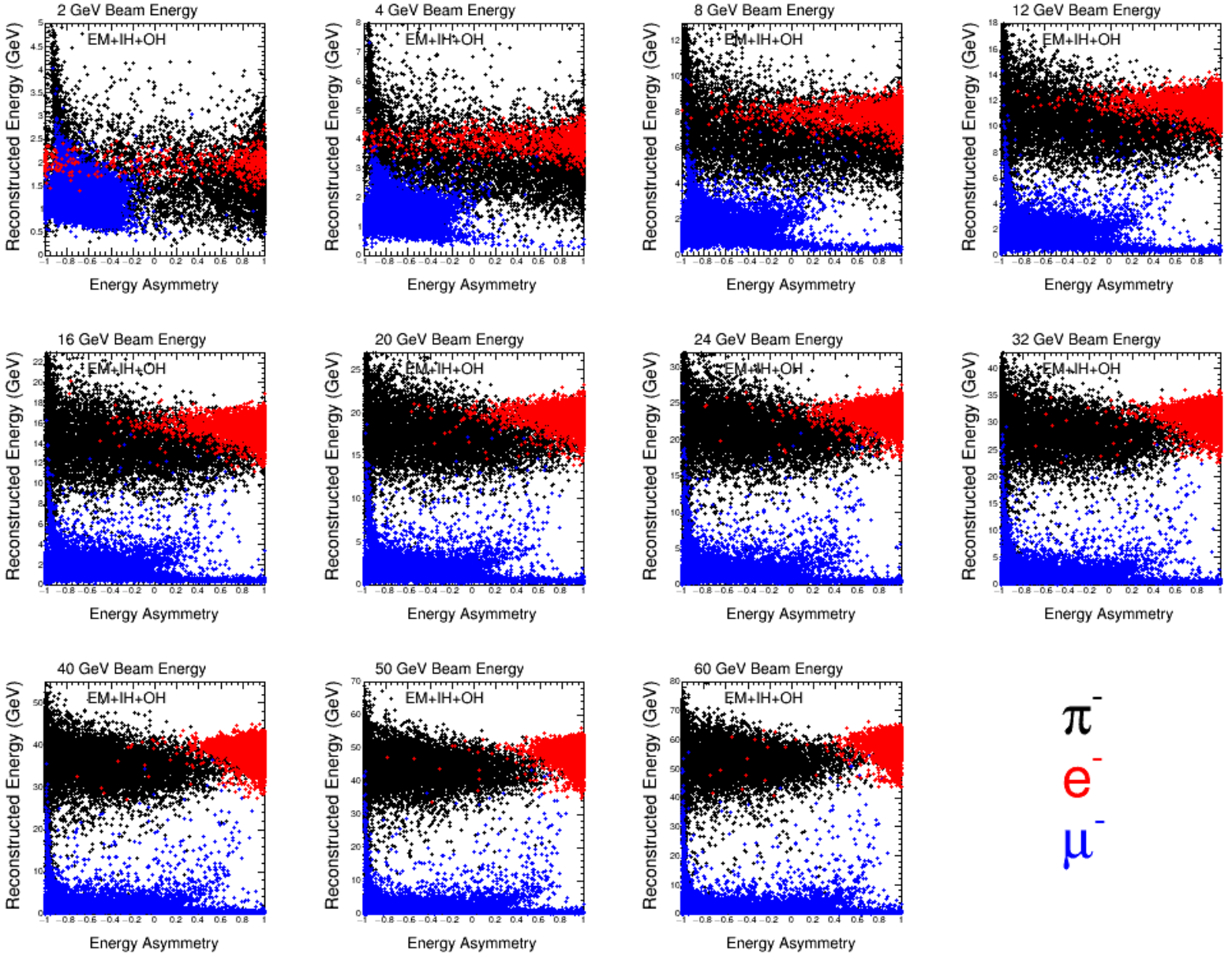


Energy Linearity (EMCal + Inner + Outer)

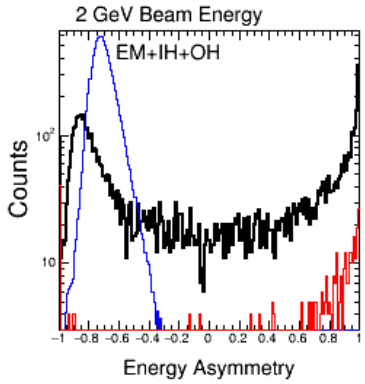


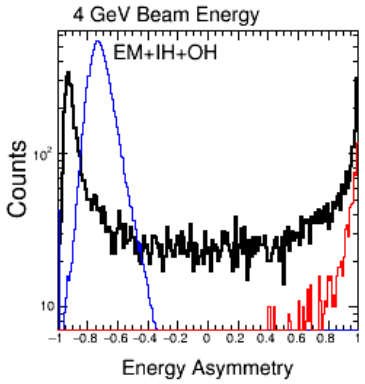
Energy Asymmetry (Case I)

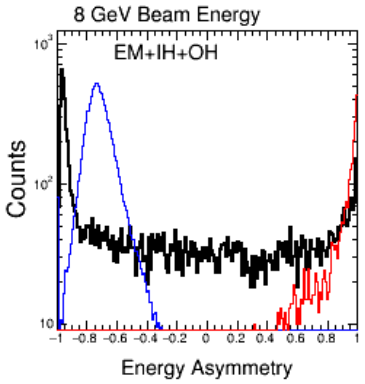
$$Asym = \frac{(E_{H1} - E_{H2})}{(E_{H1} + E_{H2})}$$

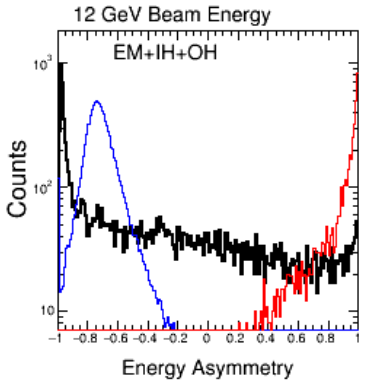


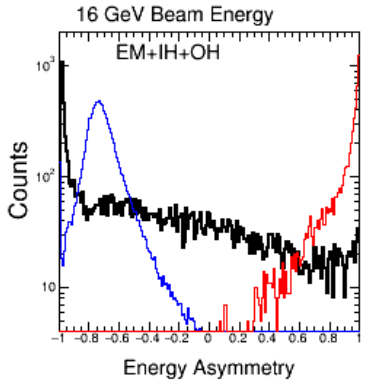
Projected Energy Asymmetry

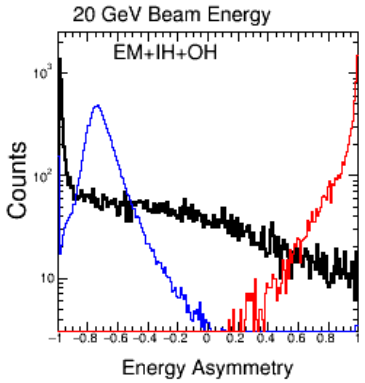


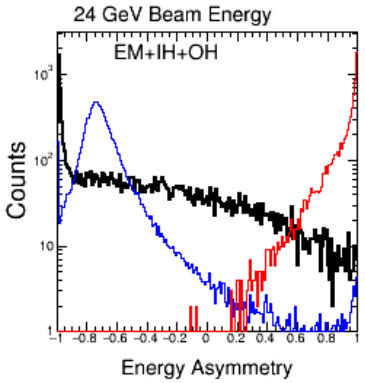


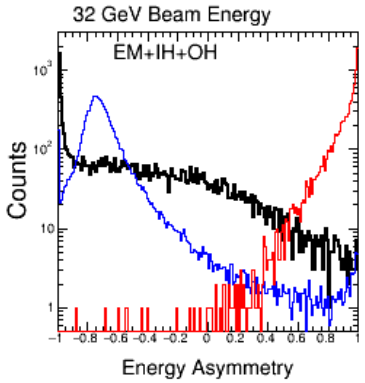


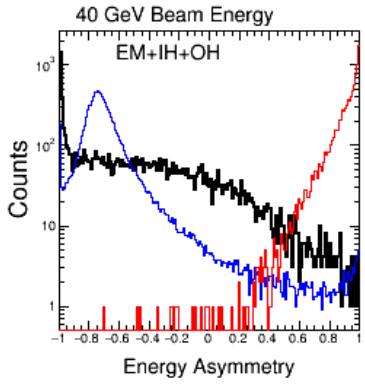


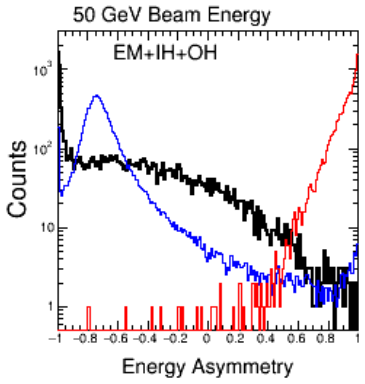


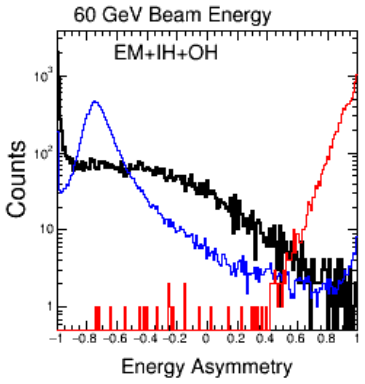






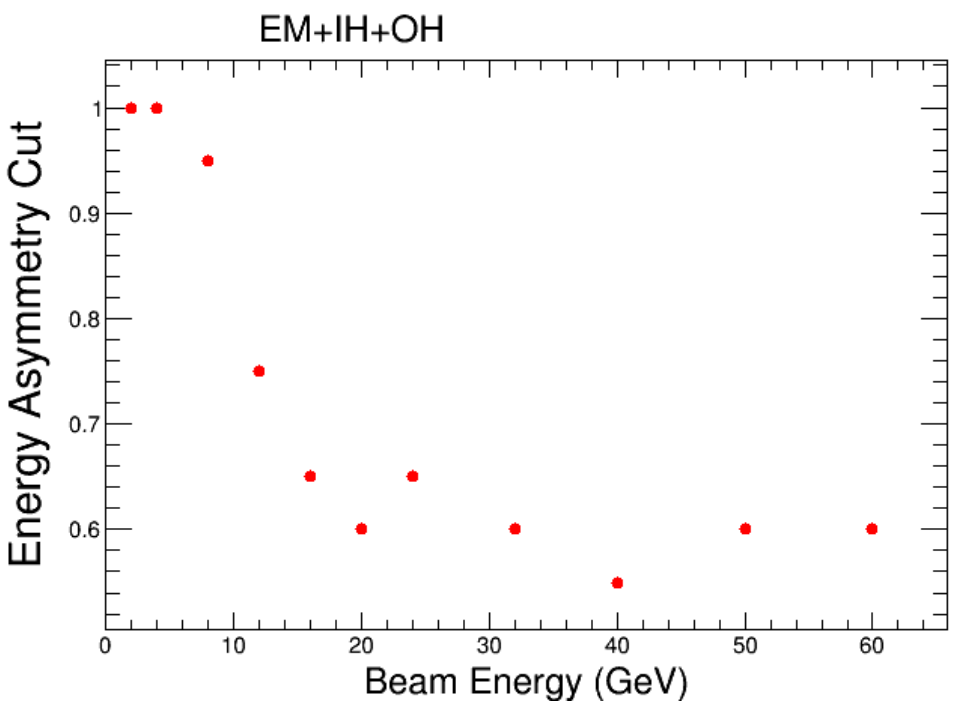


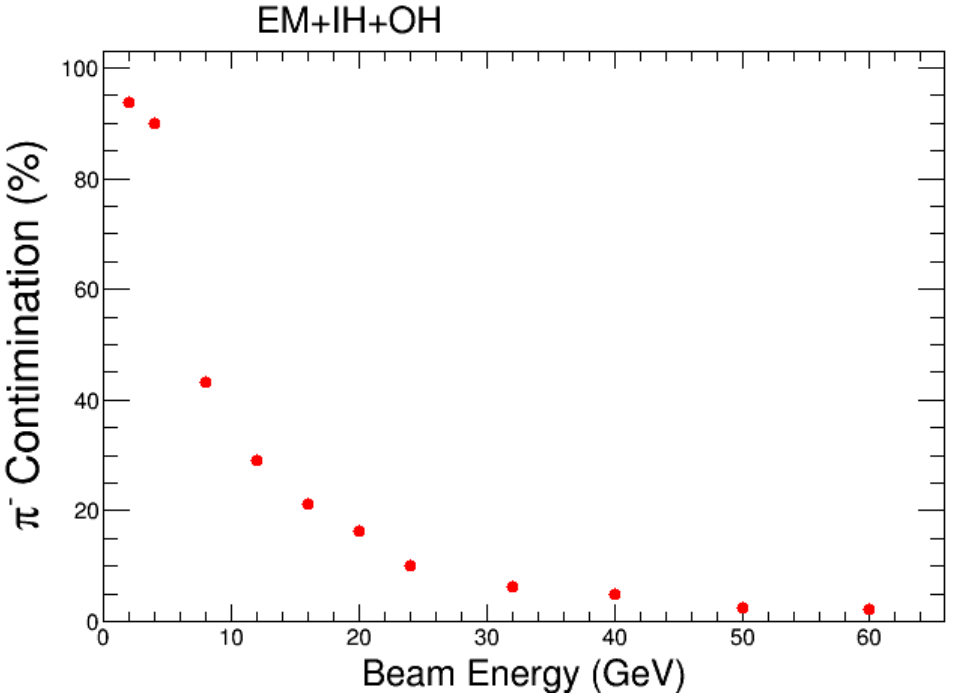




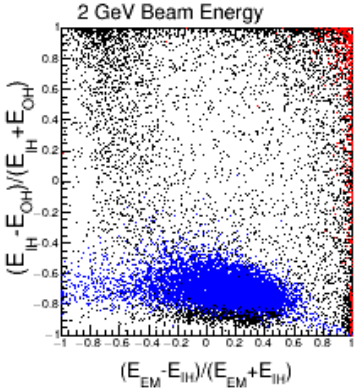
π^-
e^-
μ^-

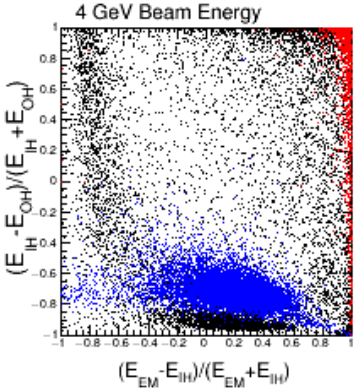
Energy Asymmetry Cut for e^-

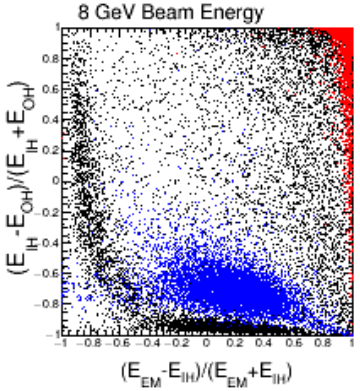


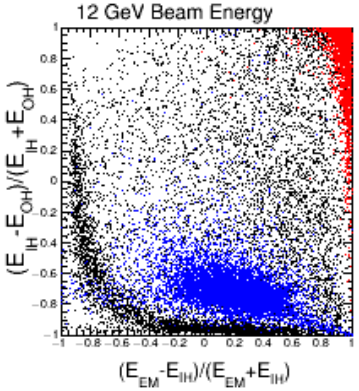


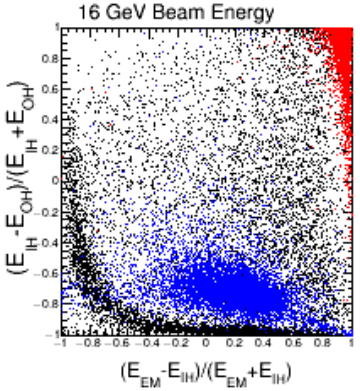
Energy Asymmetry (Case II)

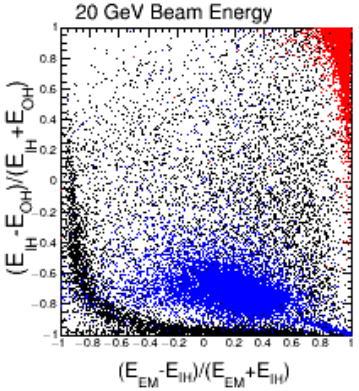


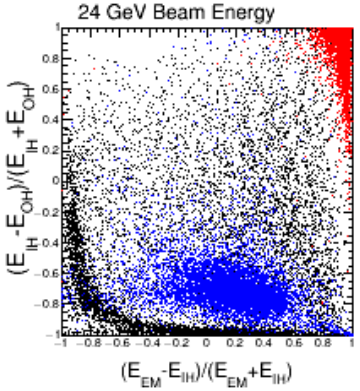


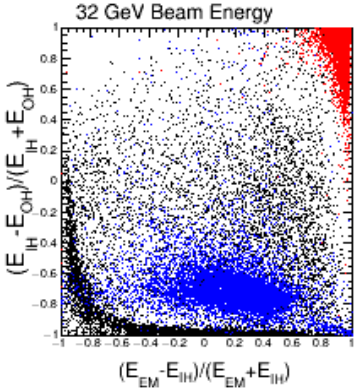


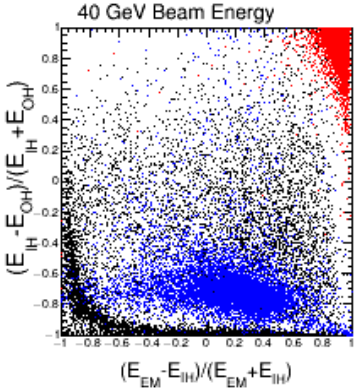


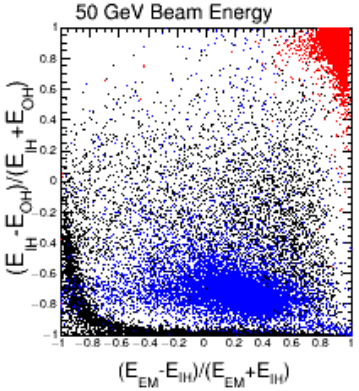


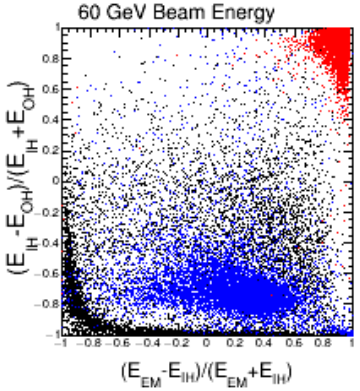












π^-

e^-

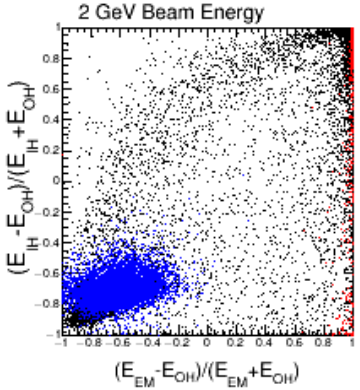
μ^-

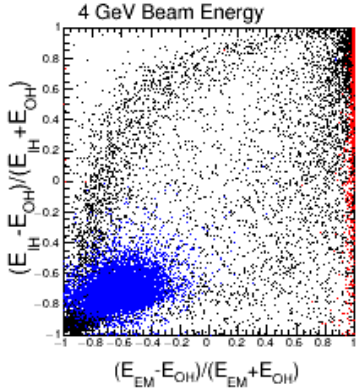
$$\frac{E_{IH}-E_{OH}}{E_{IH}+E_{OH}}$$

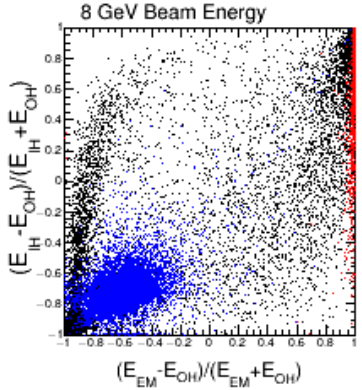
vs

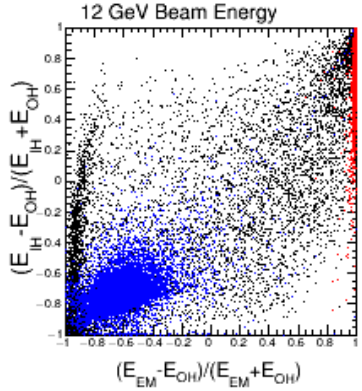
$$\frac{E_{EM}-E_{IH}}{E_{EM}+E_{IH}}$$

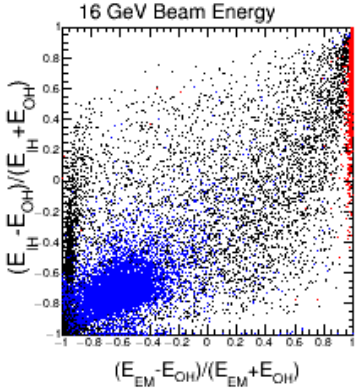
Energy Asymmetry (Case III)

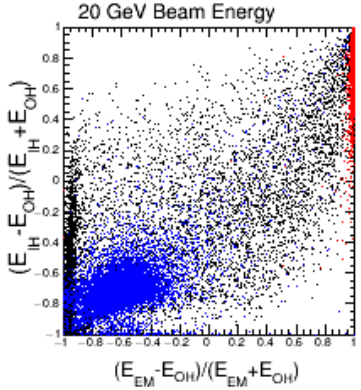


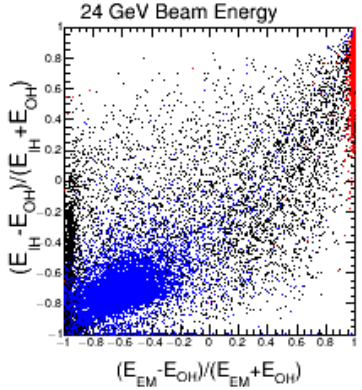


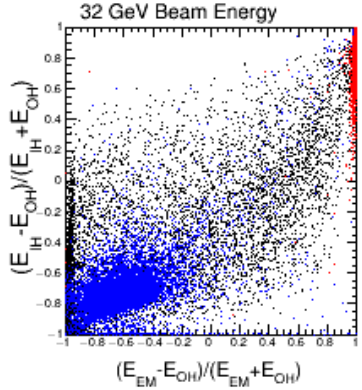


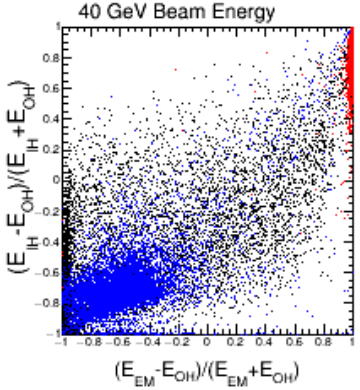


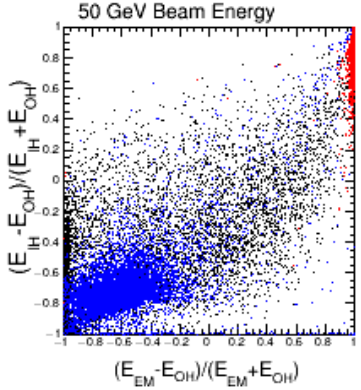


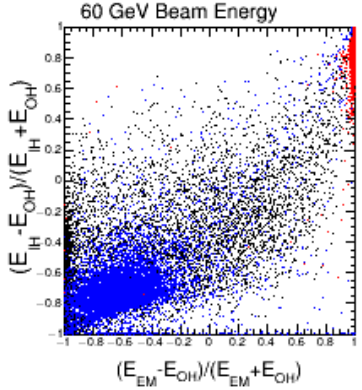








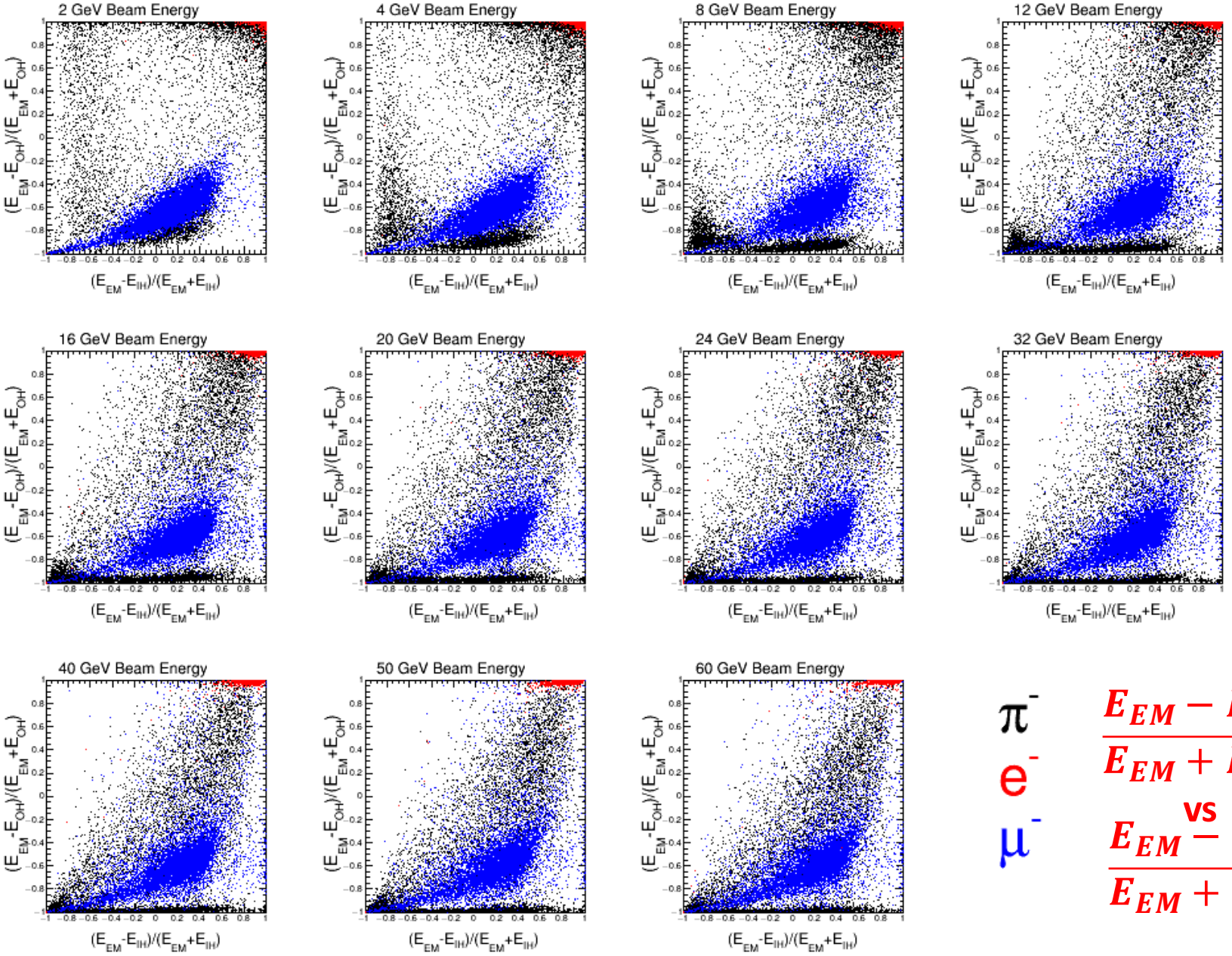




π^-
e^-
μ^-

$$\frac{E_{IH}-E_{OH}}{E_{IH}+E_{OH}} \text{ vs } \frac{E_{EM}-E_{OH}}{E_{EM}+E_{OH}}$$

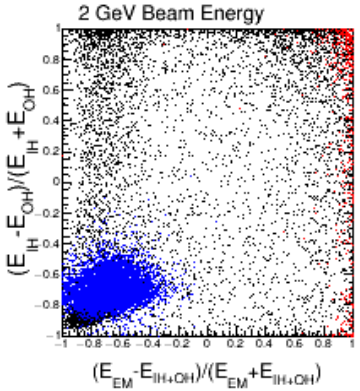
Energy Asymmetry (Case IV)

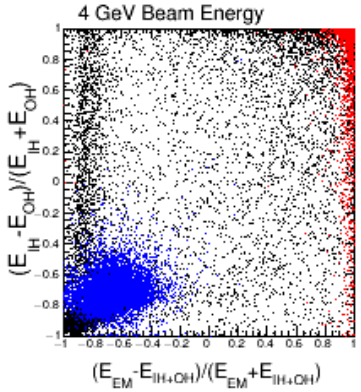


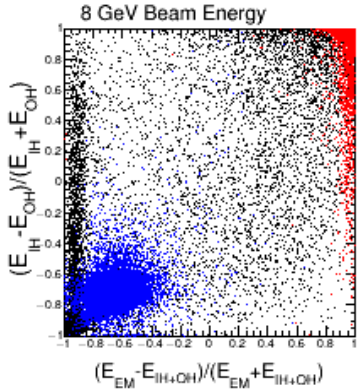
π^- e^- μ^-

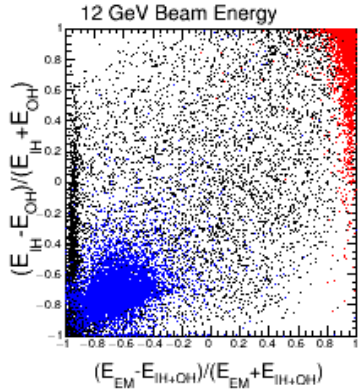
$$\frac{E_{EM}-E_{OH}}{E_{EM}+E_{OH}} \text{ vs } \frac{E_{EM}-E_{IH}}{E_{EM}+E_{IH}}$$

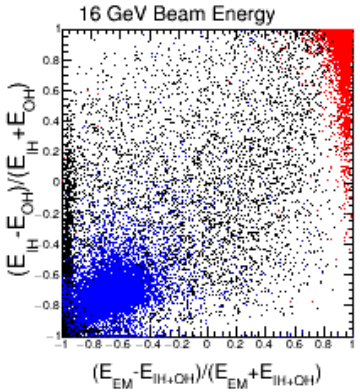
Energy Asymmetry (Case V)

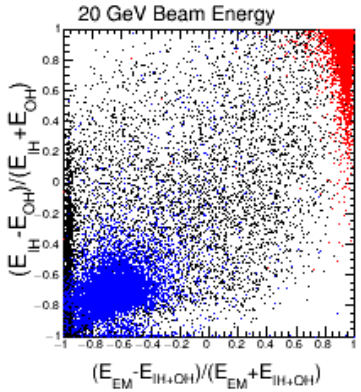


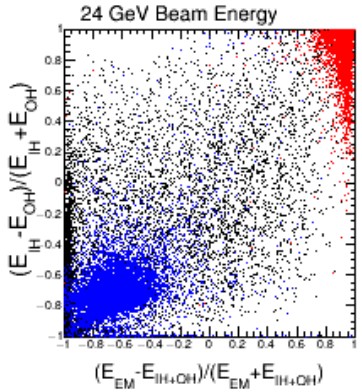


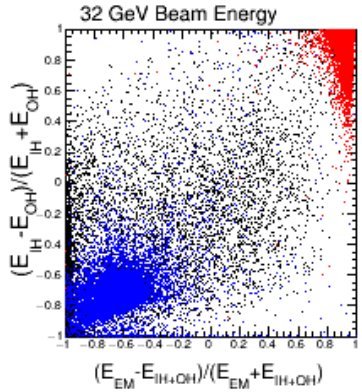


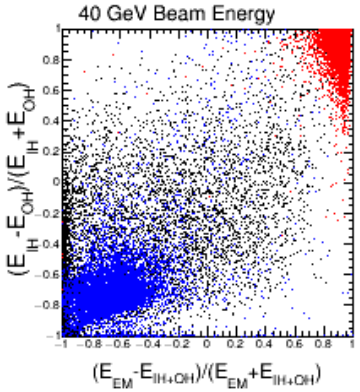


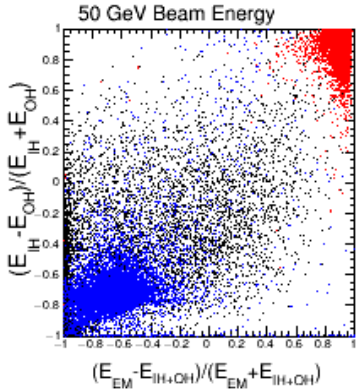


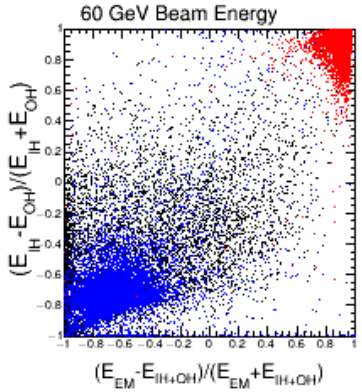












π^- $\dfrac{E_{IH}-E_{OH}}{E_{IH}+E_{OH}}$

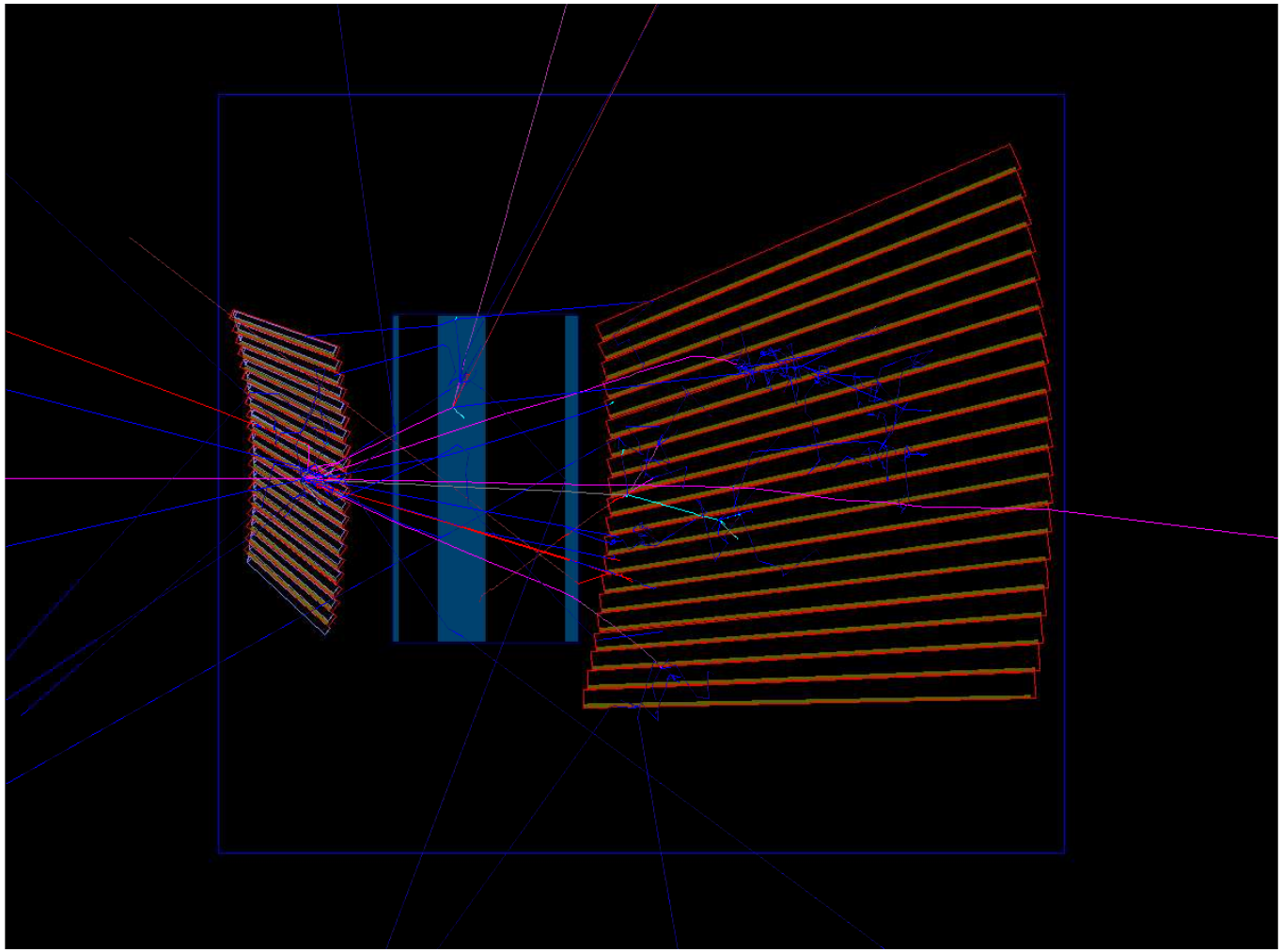
e^- vs

μ^- $\dfrac{E_{EM}-E_{IH}-E_{OH}}{E_{EM}+E_{IH}+E_{OH}}$

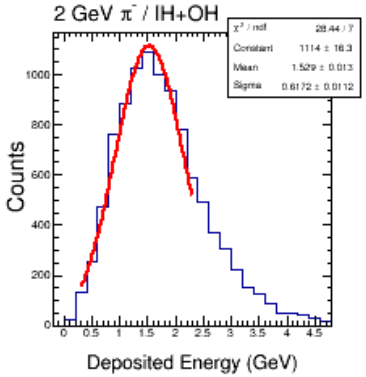
Excluding EMCal

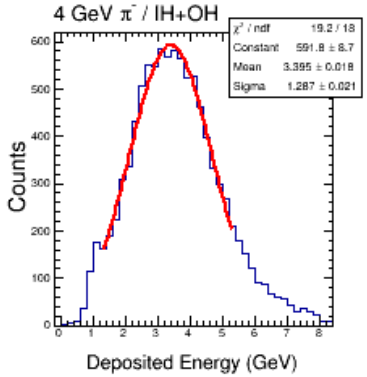
(Inner HCal + Outer HCal)

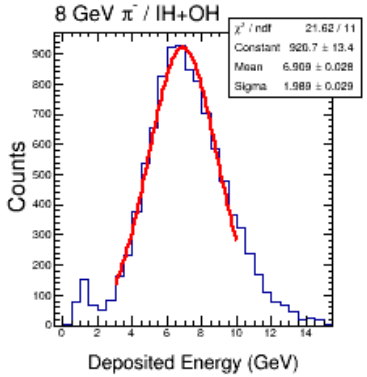
10 GeV π^-

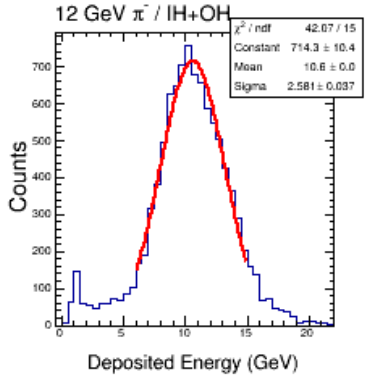


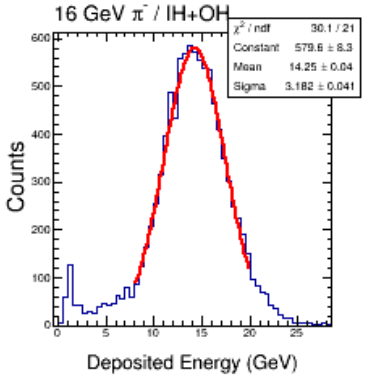
Reconstructed Energy / π^-

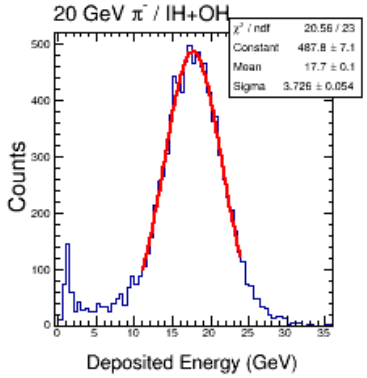


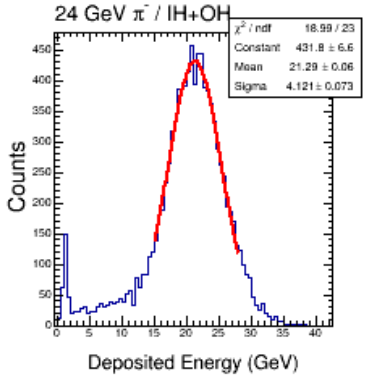


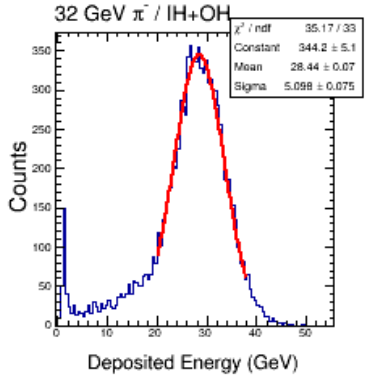


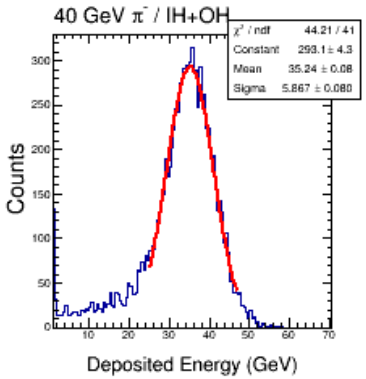


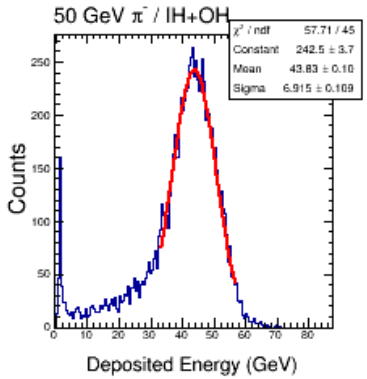


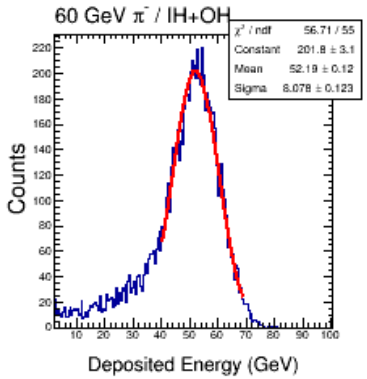




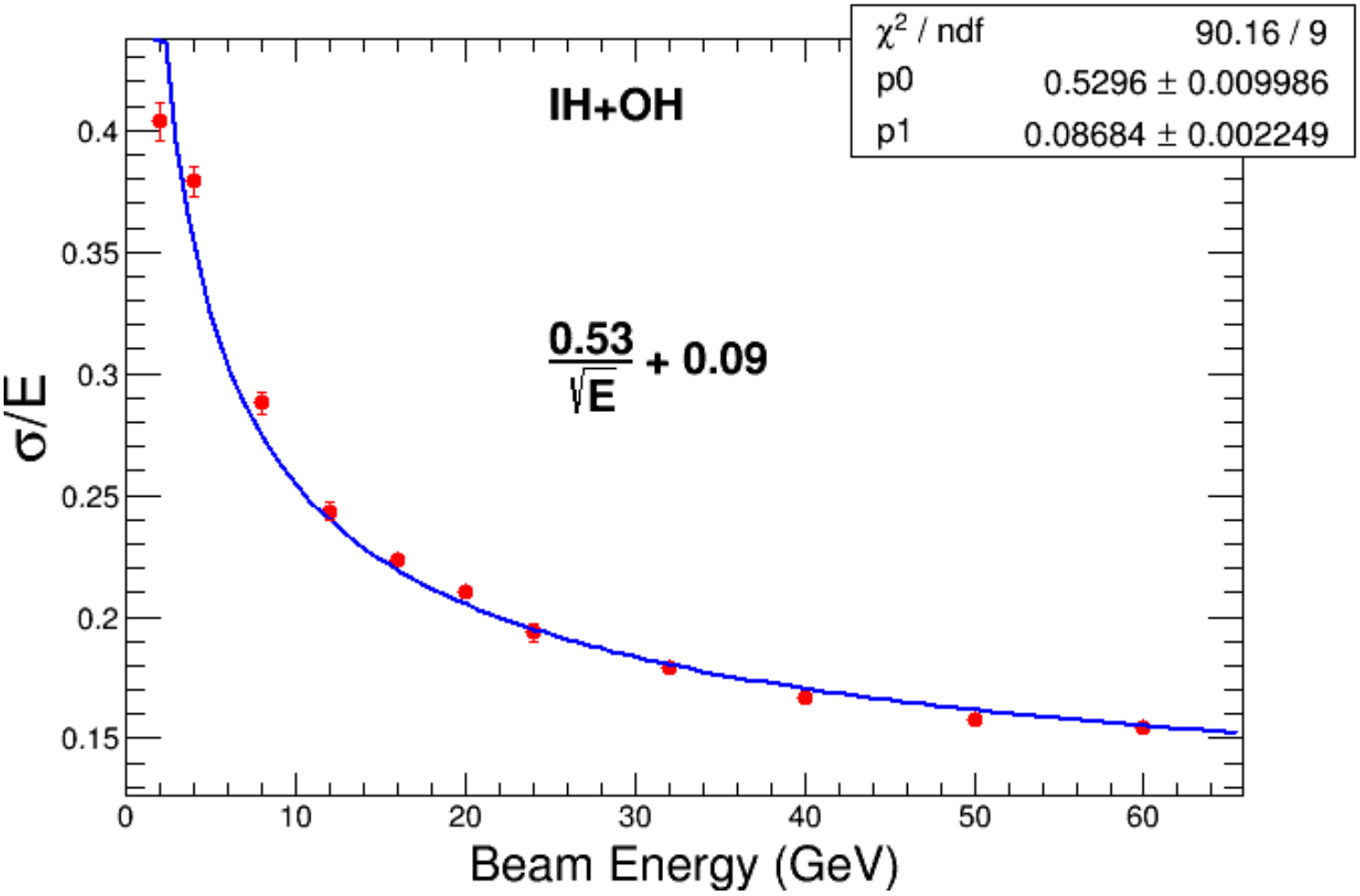




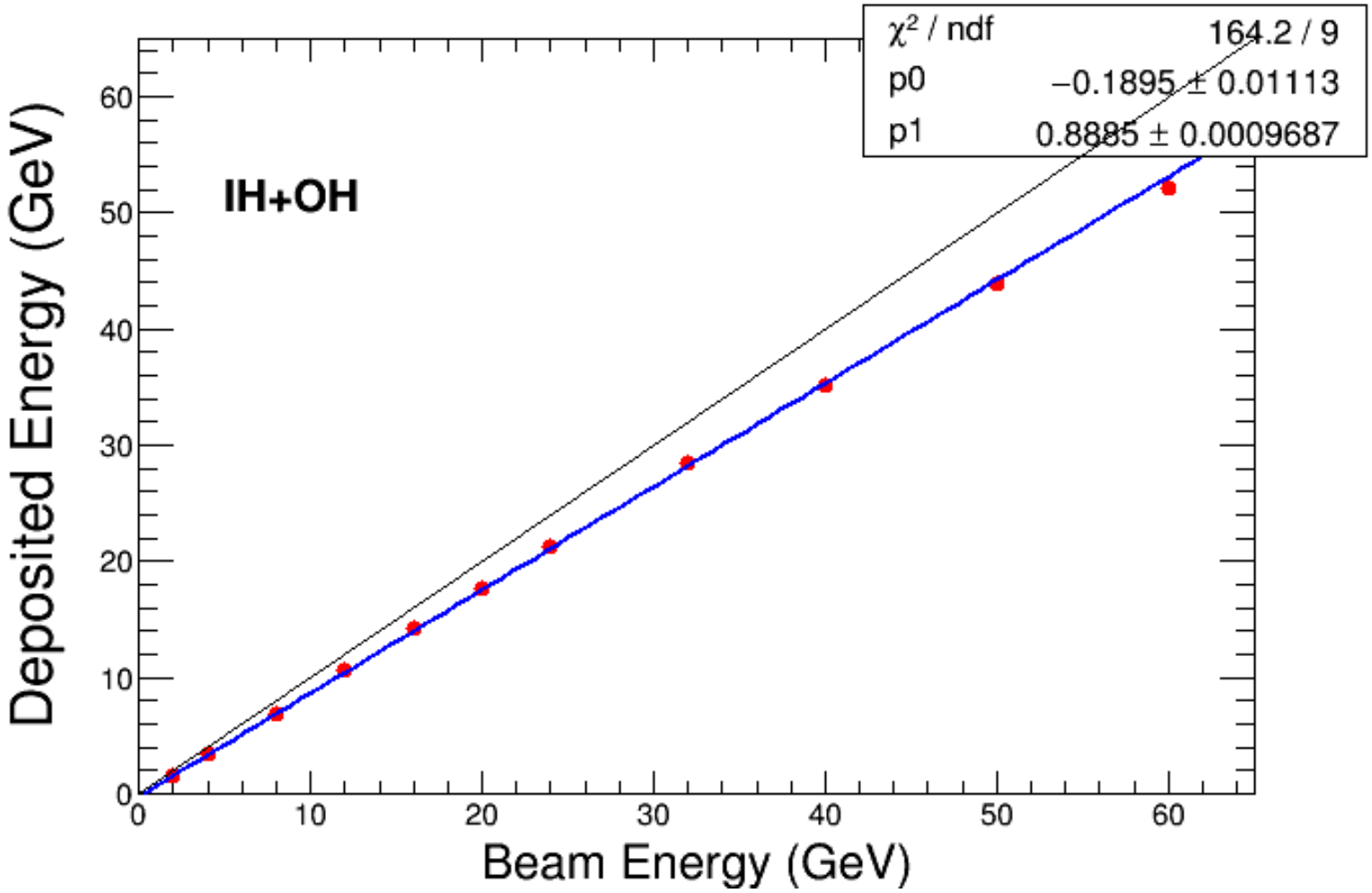




Energy Resolution (Inner + Outer)

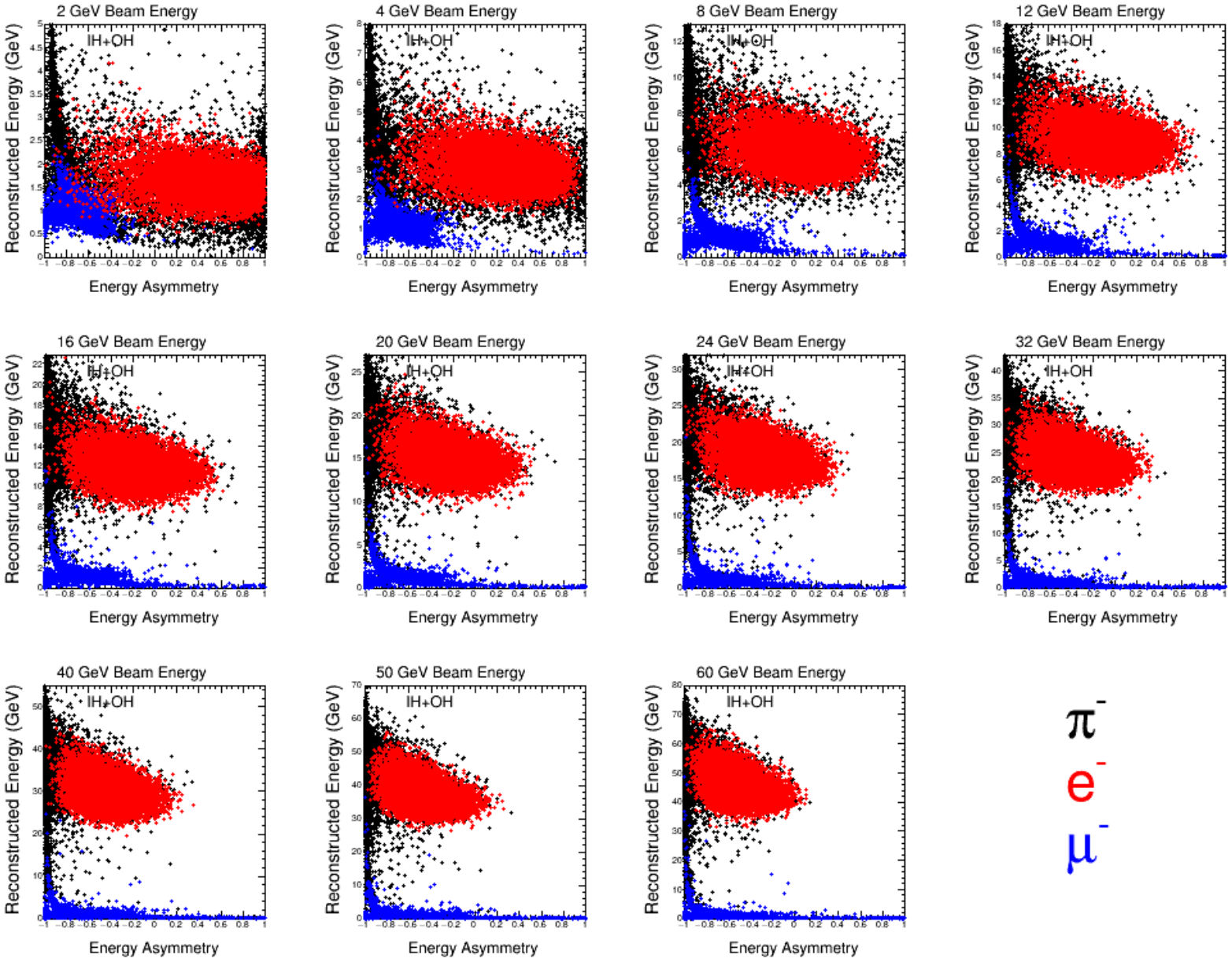


Energy Linearity (Inner + Outer)

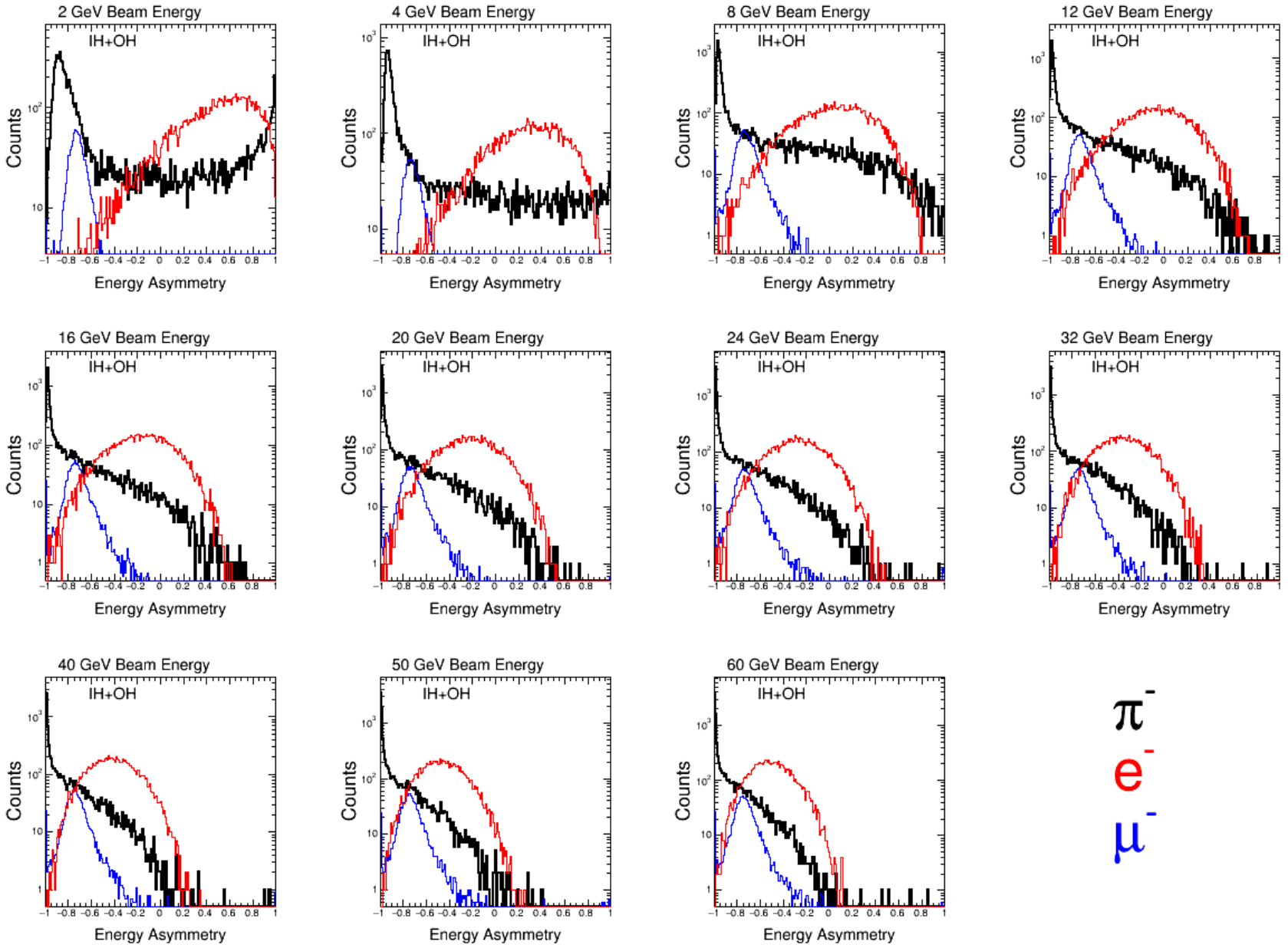


Energy Asymmetry (Inner + Outer)

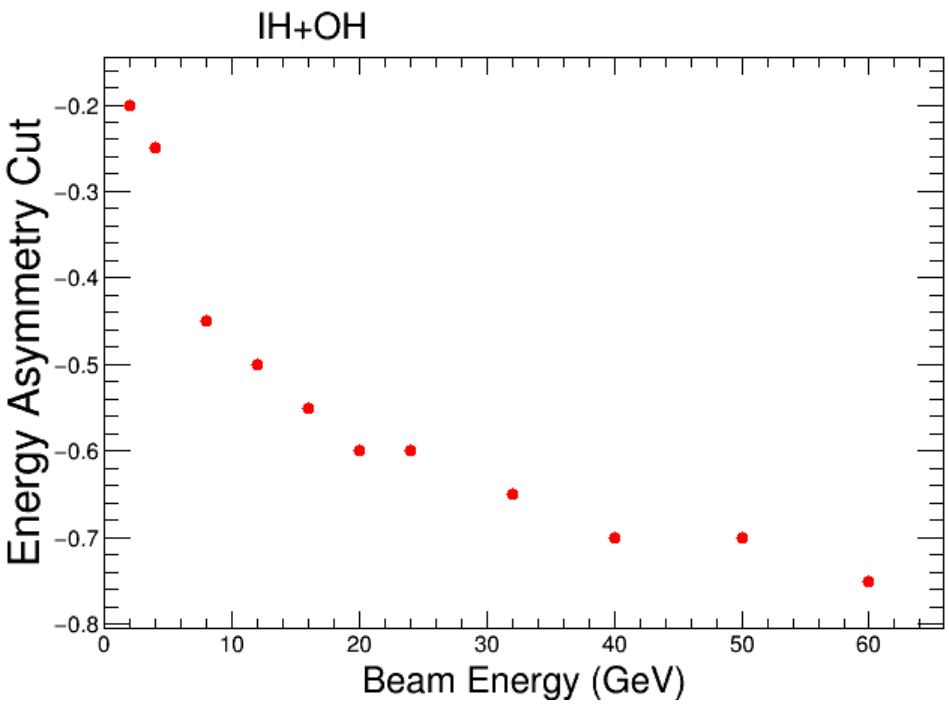
$$Asym = \frac{(E_{H1} - E_{H2})}{(E_{H1} + E_{H2})}$$

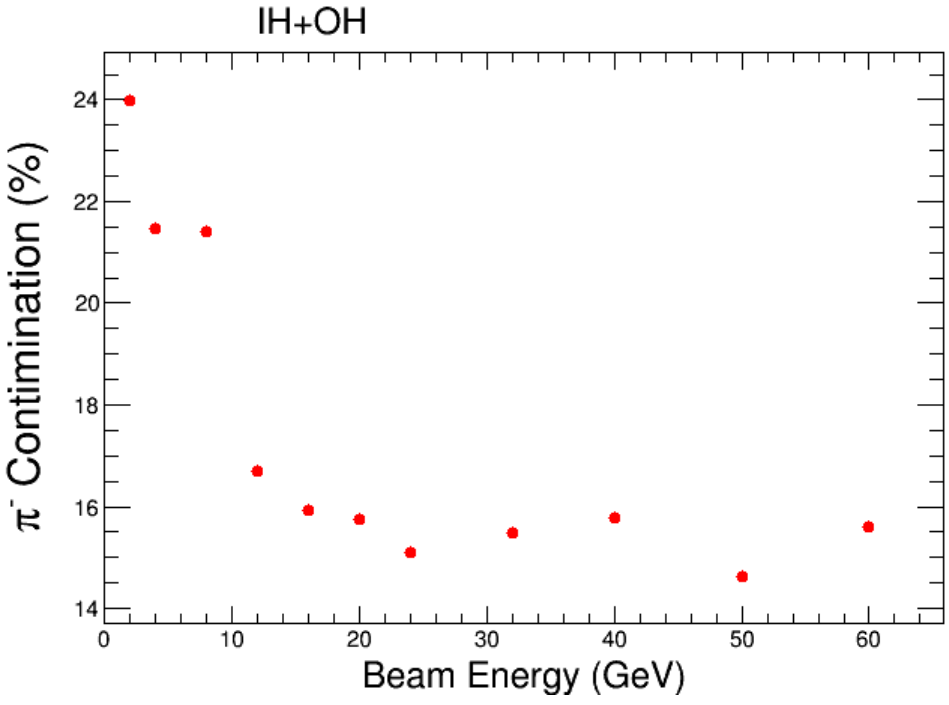


Projected Energy Asymmetry (Inner + Outer)



Energy Asymmetry Cut for e^-

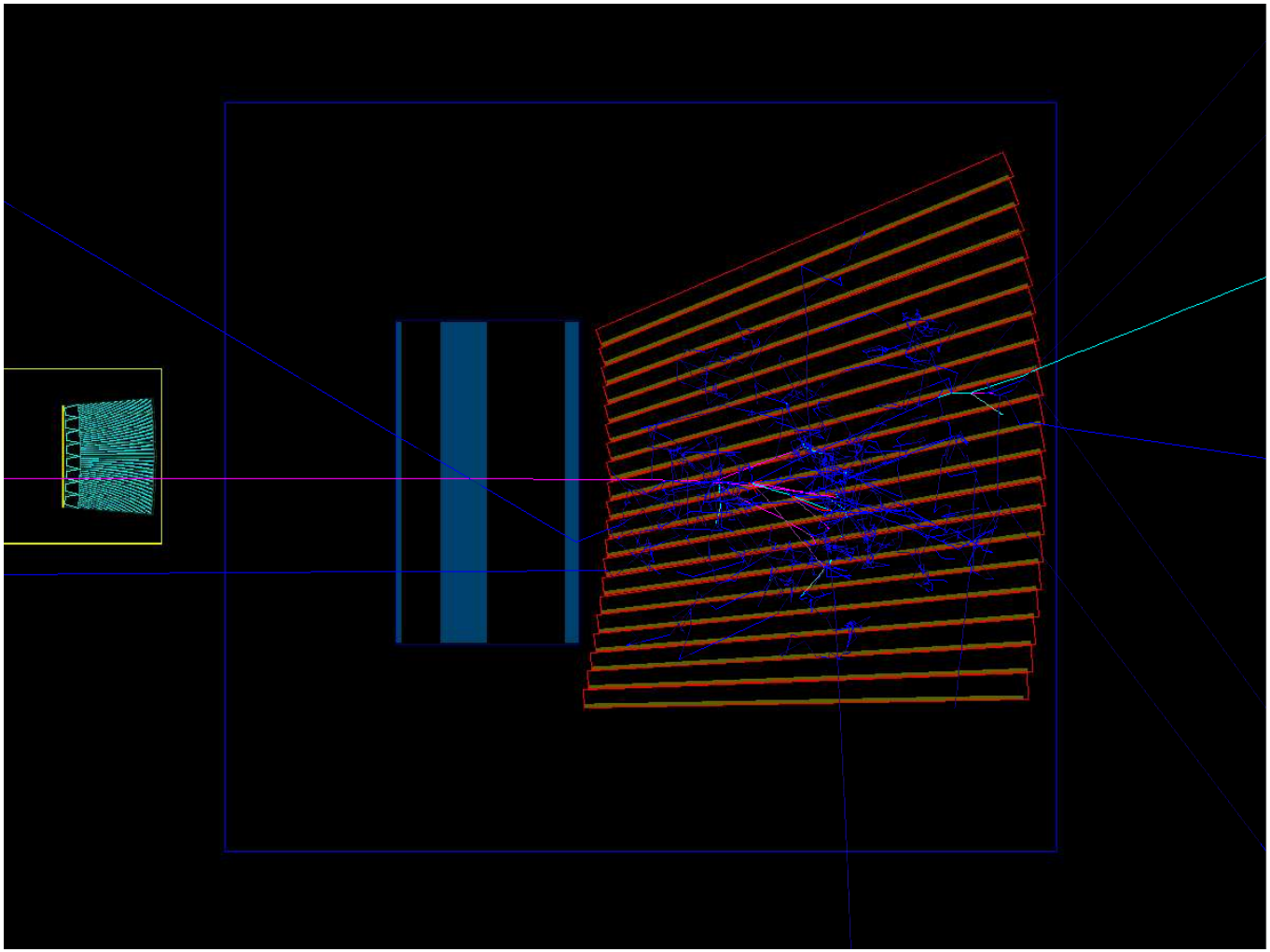




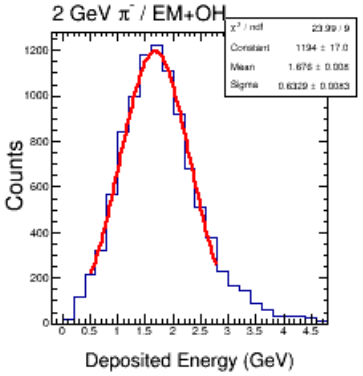
Excluding Inner HCal

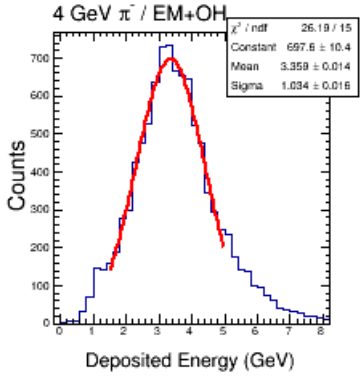
(EMCal + Outer HCal)

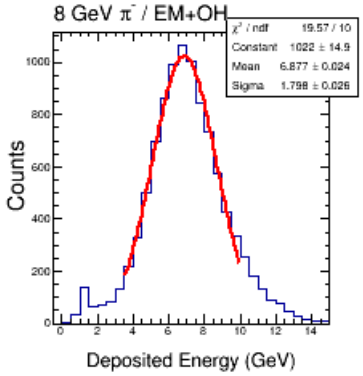
10 GeV π^-

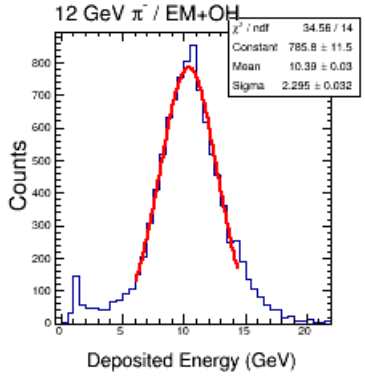


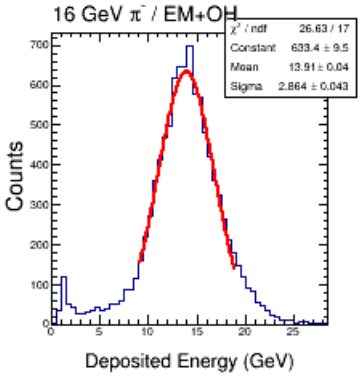
Reconstructed Energy / π^-

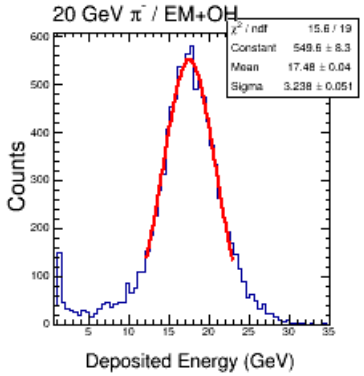


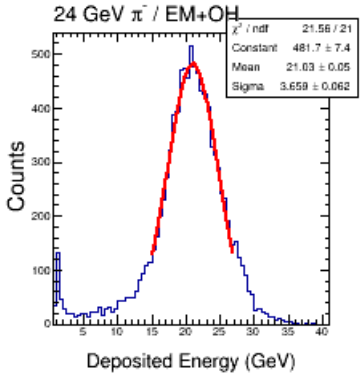


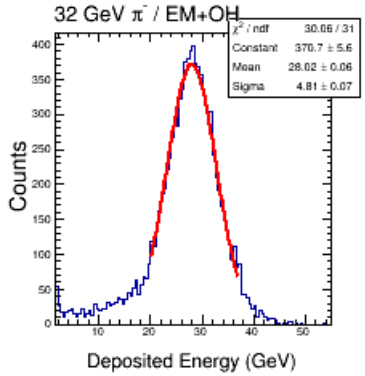


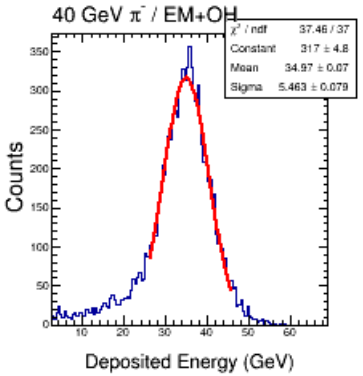


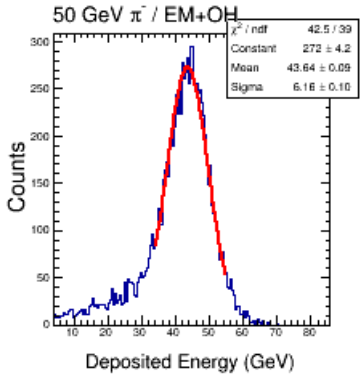


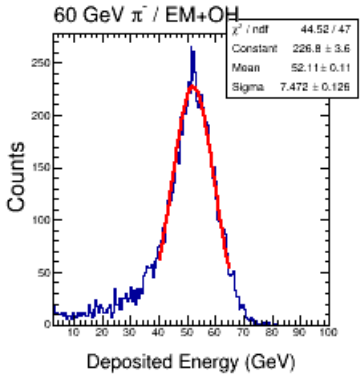




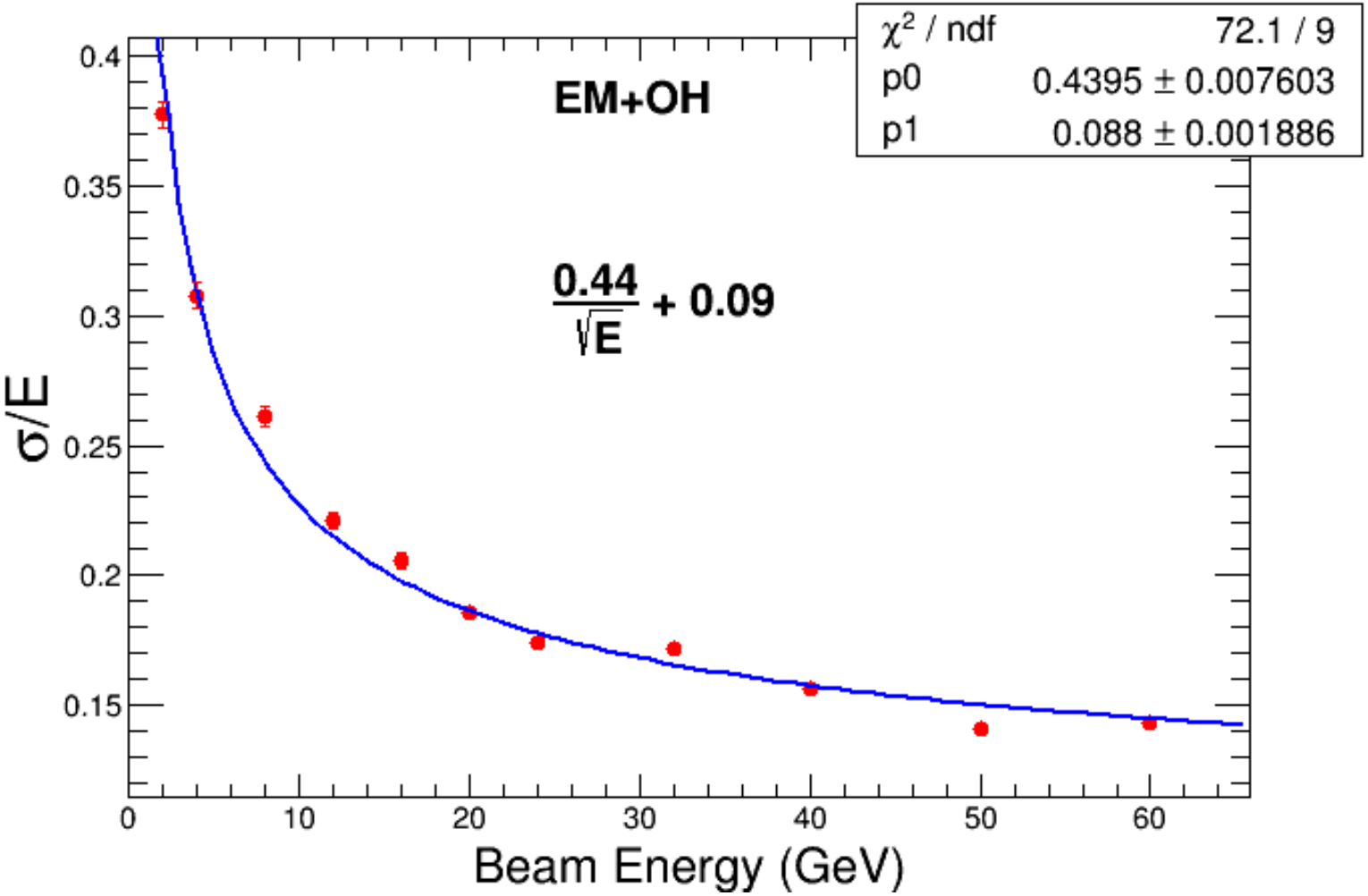




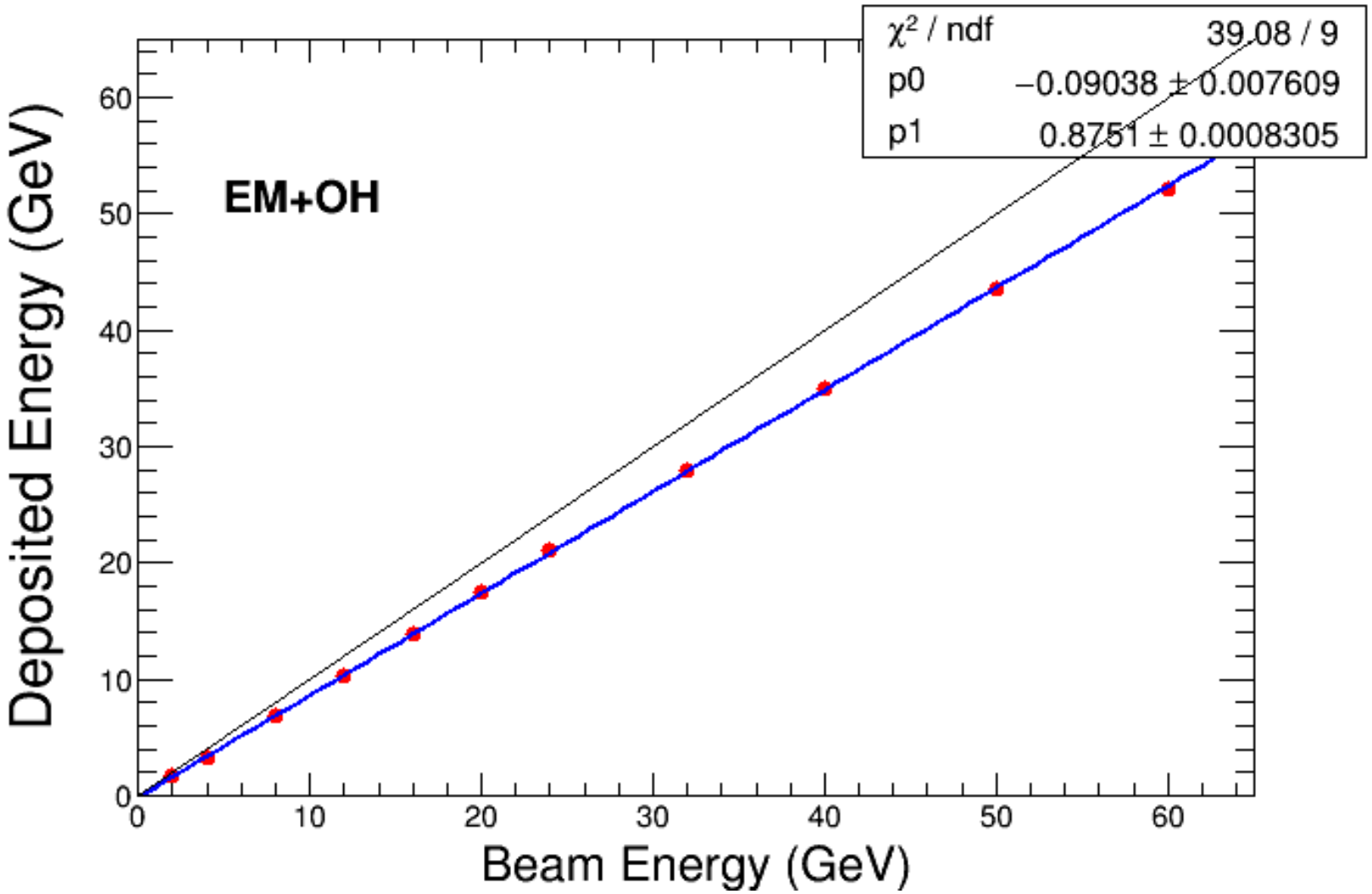




Energy Resolution (EMCal + Outer)

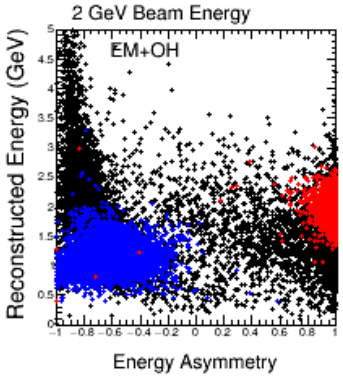


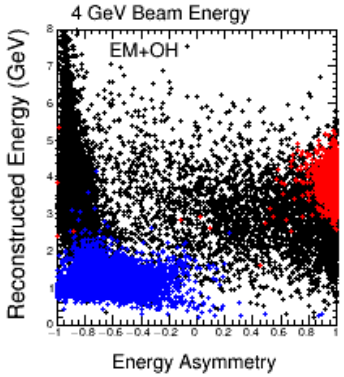
Energy Linearity (EMCal + Outer)

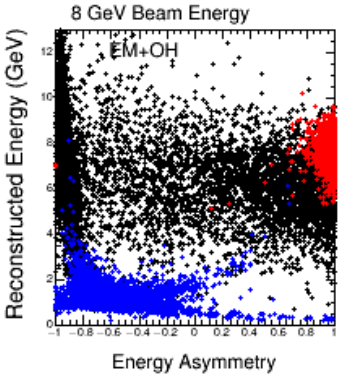


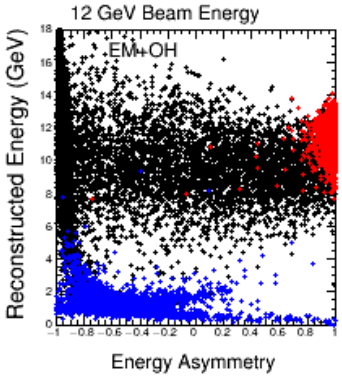
Energy Asymmetry (EMCal + Outer)

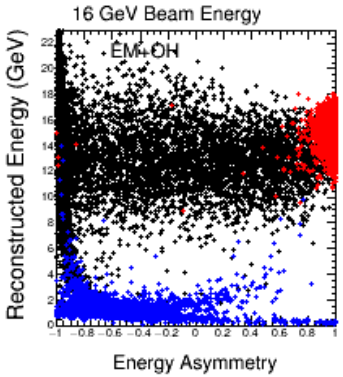
$$Asym = \frac{(E_{EM} - E_{H2})}{(E_{EM} + E_{H2})}$$

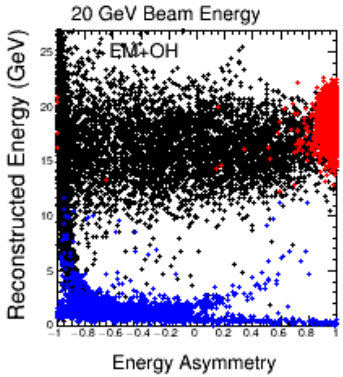


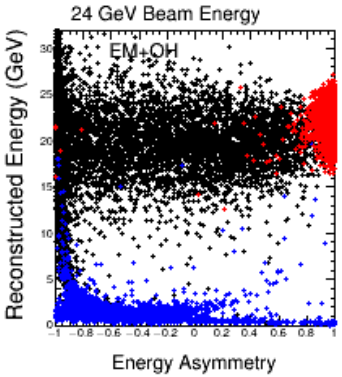


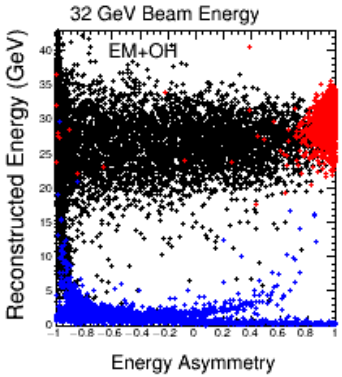


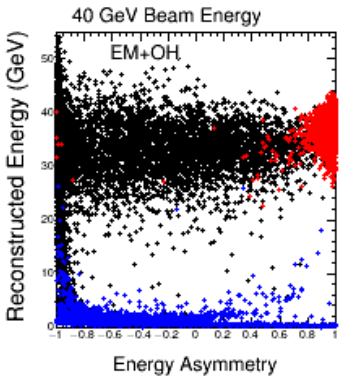


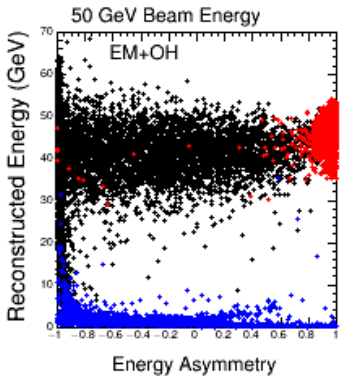


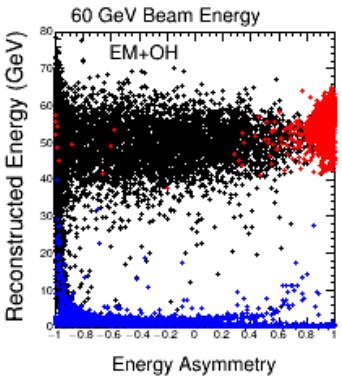






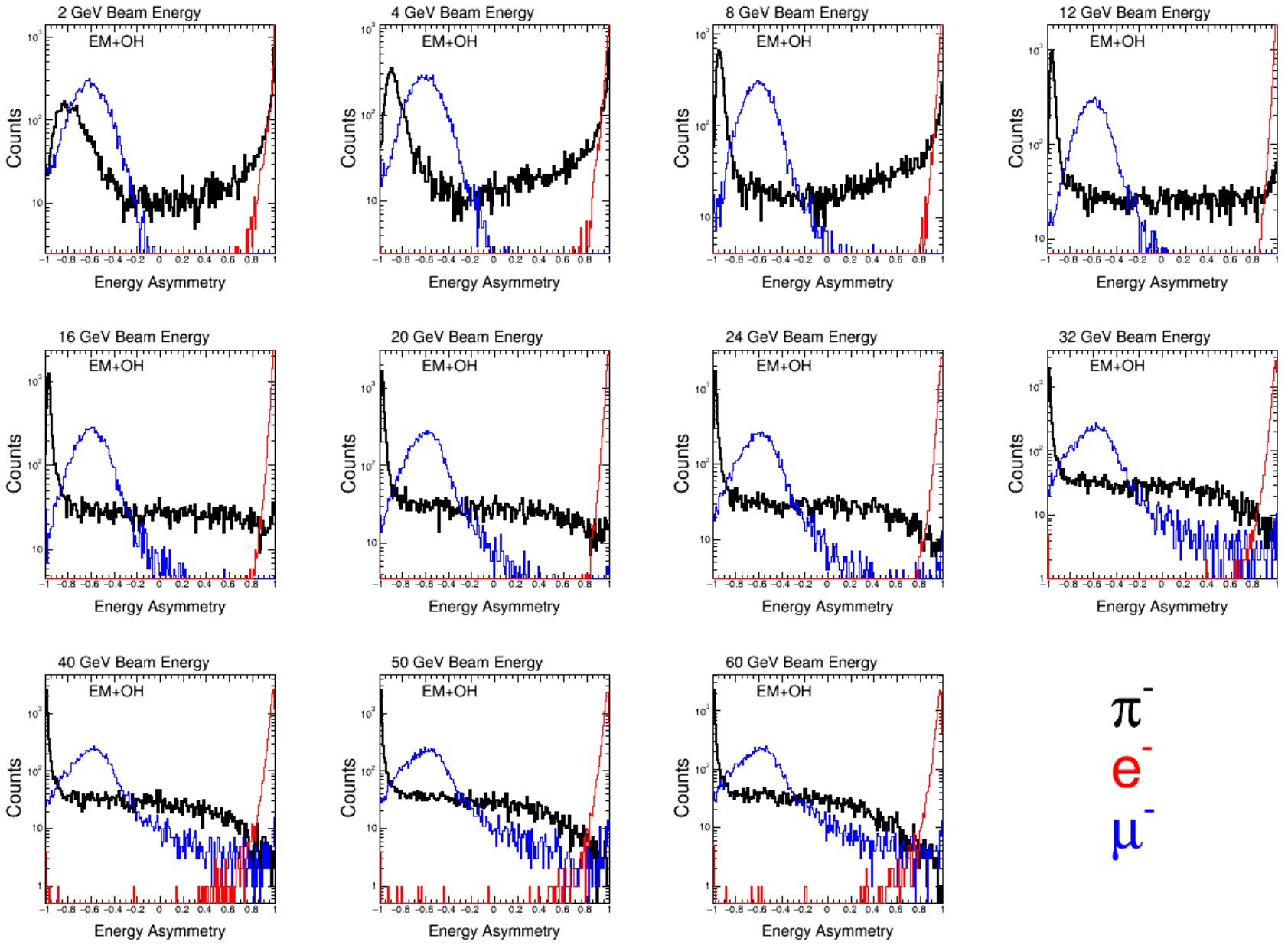




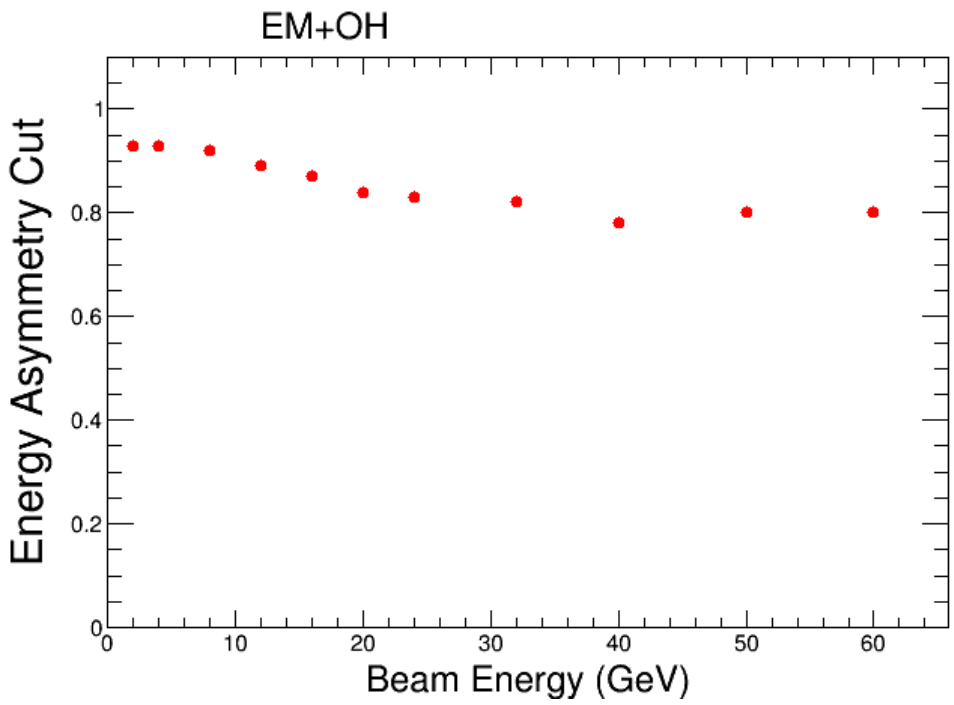


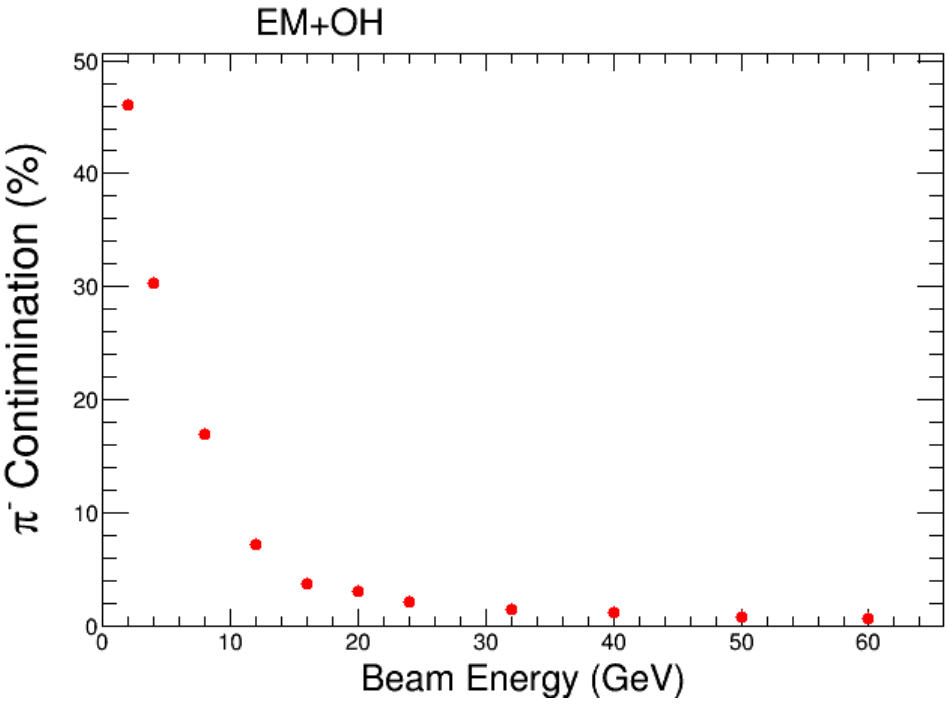
π^-
e^-
μ^-

Projected Energy Asymmetry (EMCal + Outer)



Energy Asymmetry Cut for e^-





Summary

	Linearity (slope)	Resolution [a,b]	Asymmetry Cut	π^- cont. (%) E>8 GeV
EM + IH + OH	0.89	0.44, 0.06	~0.6	15
IH + OH	0.89	0.53, 0.09	~-0.65	16
EM + OH	0.88	0.44, 0.09	~0.85	4

- To determine the resolution, fitted with $f(E) = a/\sqrt{E} + b$
- The asymmetry cut was determined from the projected plot where the cut where black curve (π^- distribution) starts getting below the read one (e^- distribution)

To-do

- Refine the simulation to match with the data.
- Detailed study of the shower energy distribution in each of the calorimeter system (energy asymmetry) to enhance PID capability.
- Need a large chunk of disk space for storing the simulated data.

Backup

Highlights from the 1st Prototype Study

Reported on July 31, 2015 at SBU sPHENIX Workshop

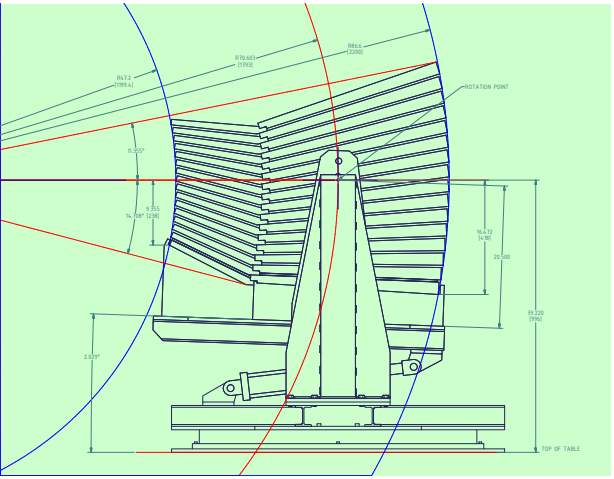
Detailed are documented in a technical note 471

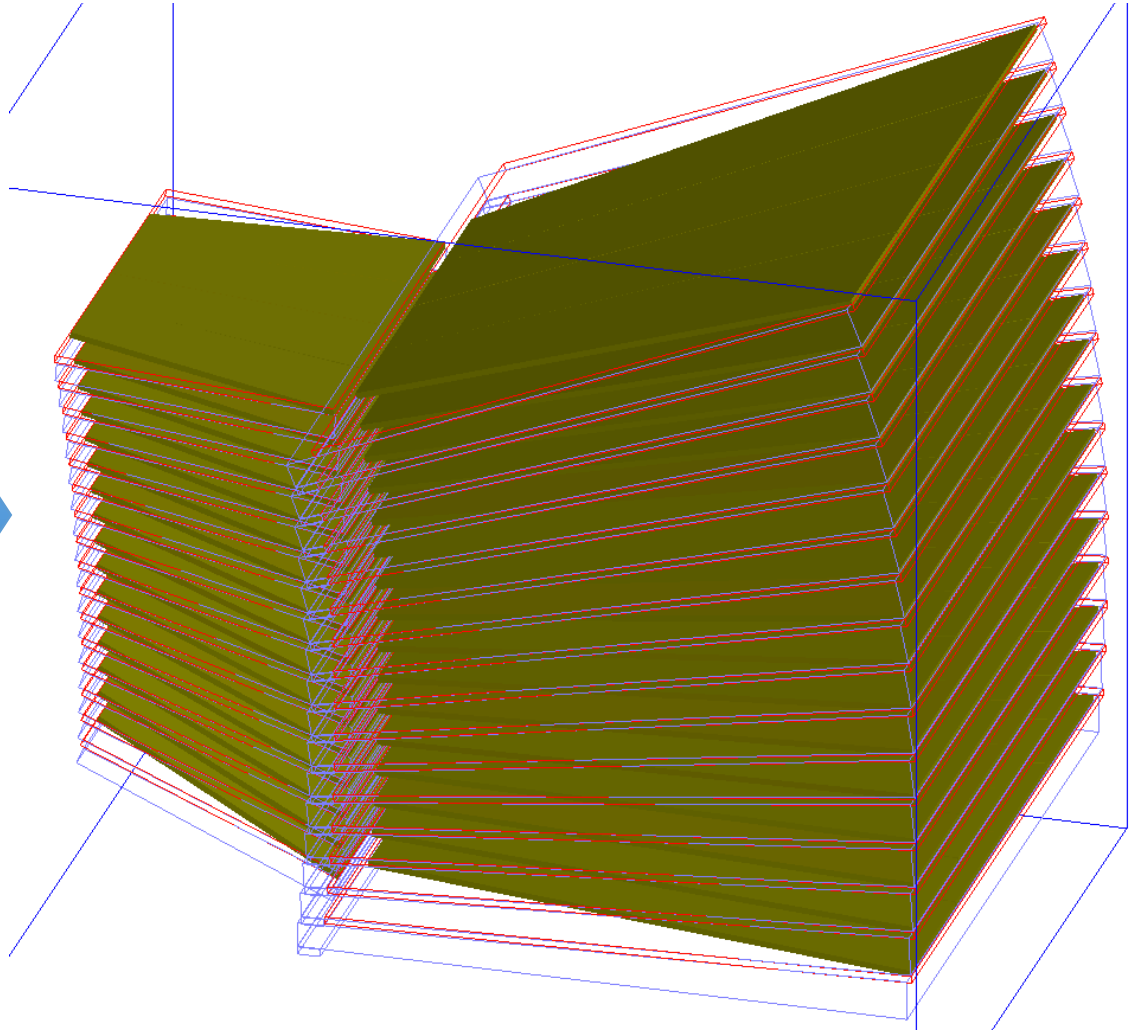
Technical Report of the sPHENIX Hadronic Calorimeter Prototype Simulation Study and the Beam Test Data Analysis

L. Xue[c], C. Aidala[e], S. Beckman[b], C. Biggs[a], S. Boose[a], M. Chiu[a], A. Franz[a], Y. Goto[g], J. Haggerty[a], X. He[c], K. Jones[a], E. Kistenev[a], B. Lenz[a], M. Lenz[a], D. Lynch[a], E. Mannel[a], M. McCumber[d], D. Morrison[a], J. Nagle[b], E. Obrien[a], C. Pinkenburg[a], S. Polizzo[a], B. Ramson[e], J. Rubin[e], R. Ruggeiro[a], A. Sickles[a], P. Stankus[a], S. Stoll[a], A. Sukhanov[a], F. Toldo[a], C. Woody[a]

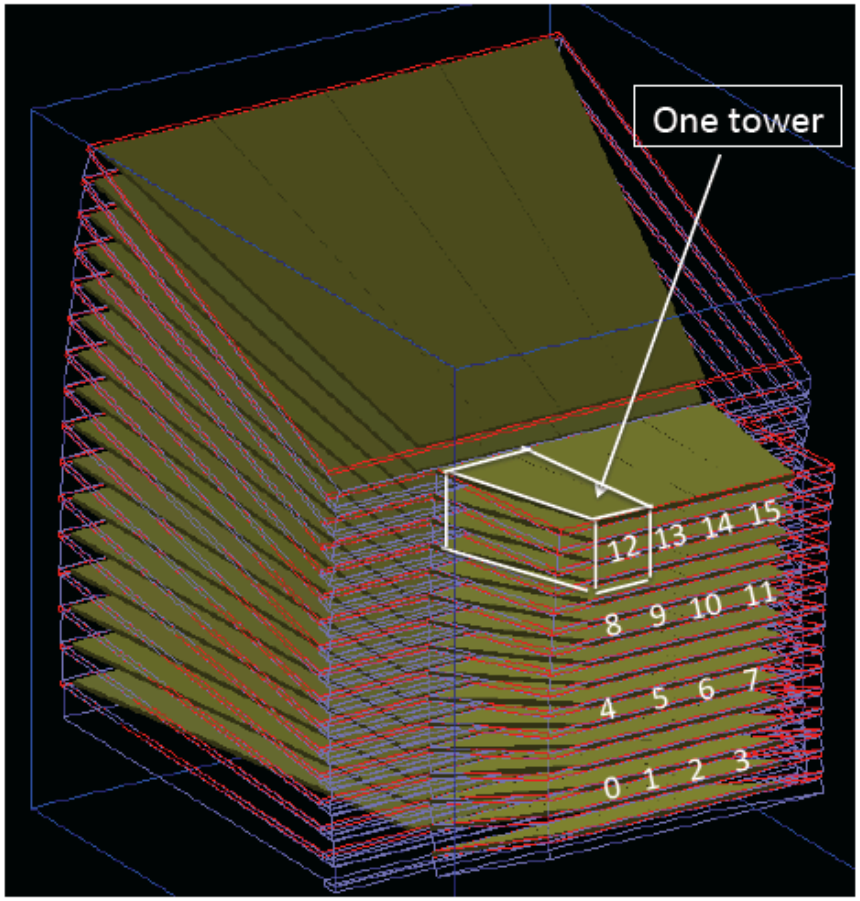
About 70 pages long

From engineering drawings to Geant4 detector construction





The most relevant terminology



Each tower is equal one readout channel (i.e., 16 towers for the inner and the same for the outer)

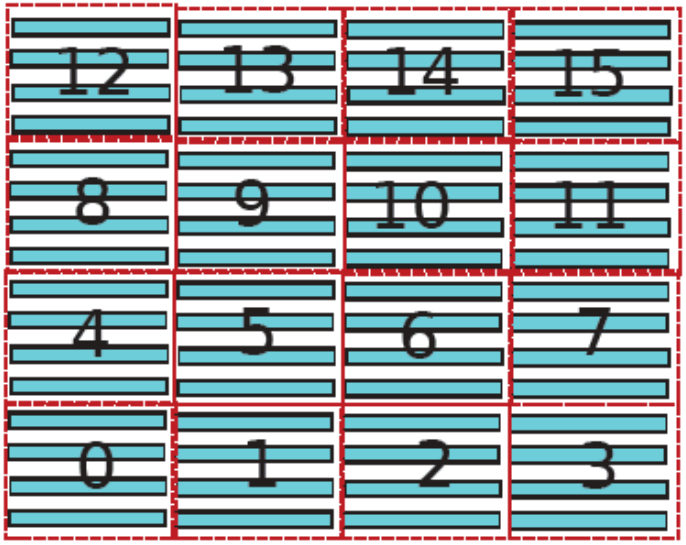
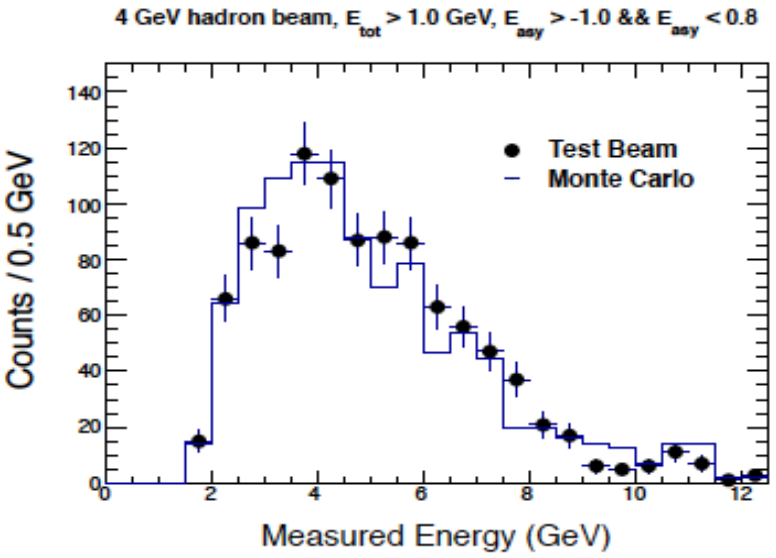
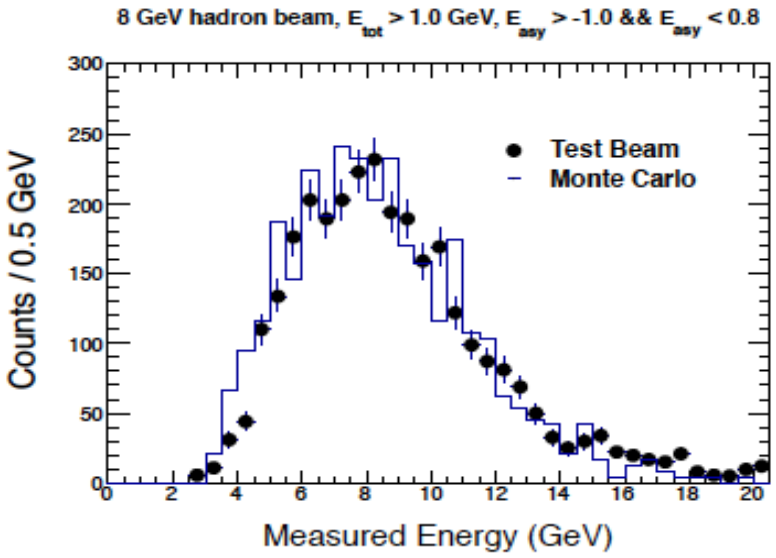
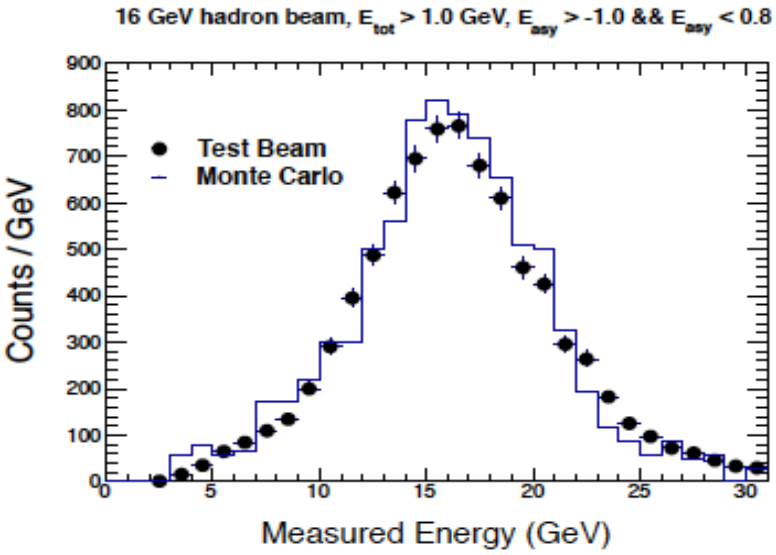


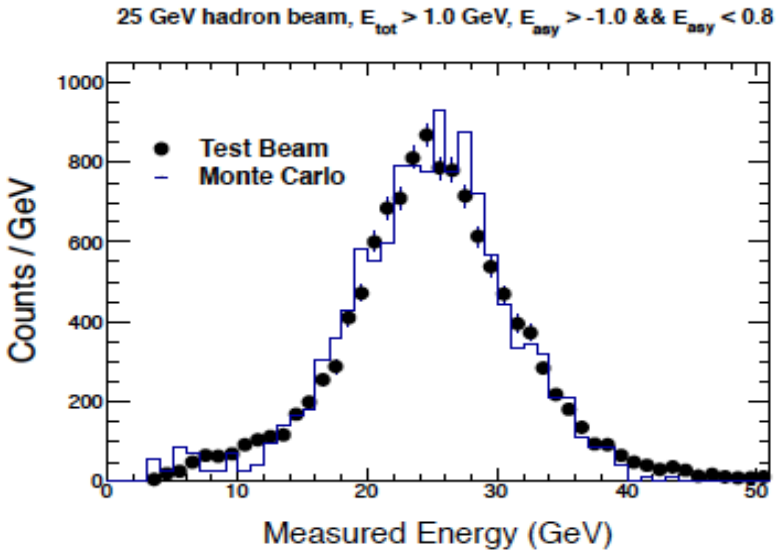
Figure 3: HCal tower layout viewed from the front both for H1 and H2.

Simulation and Data Comparison

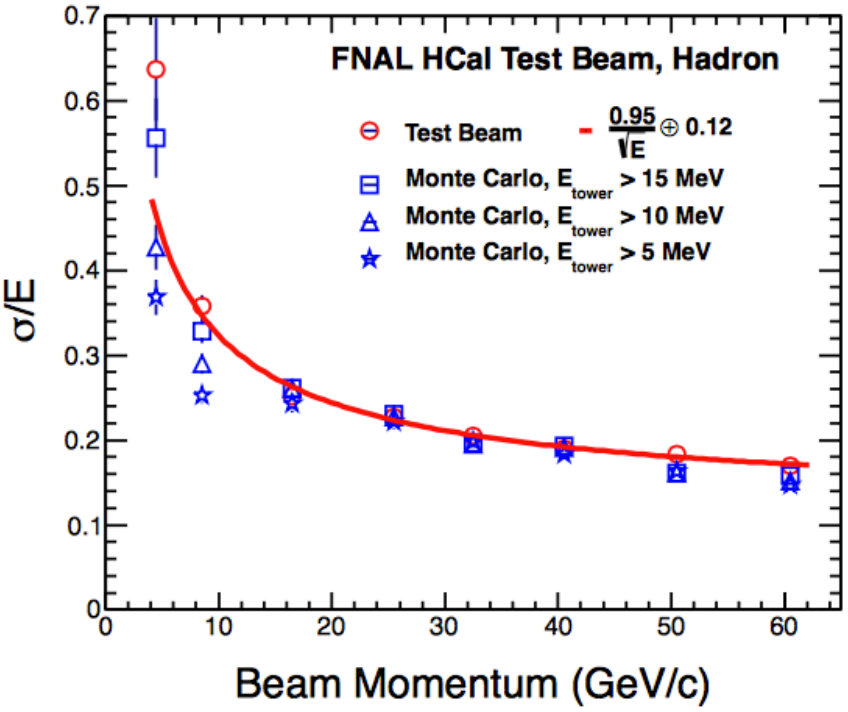


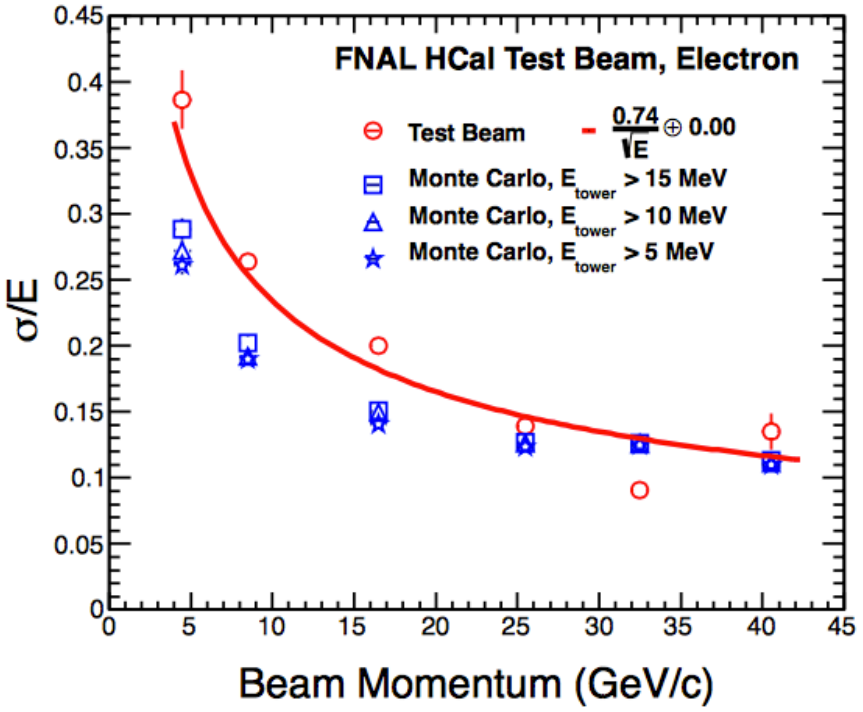






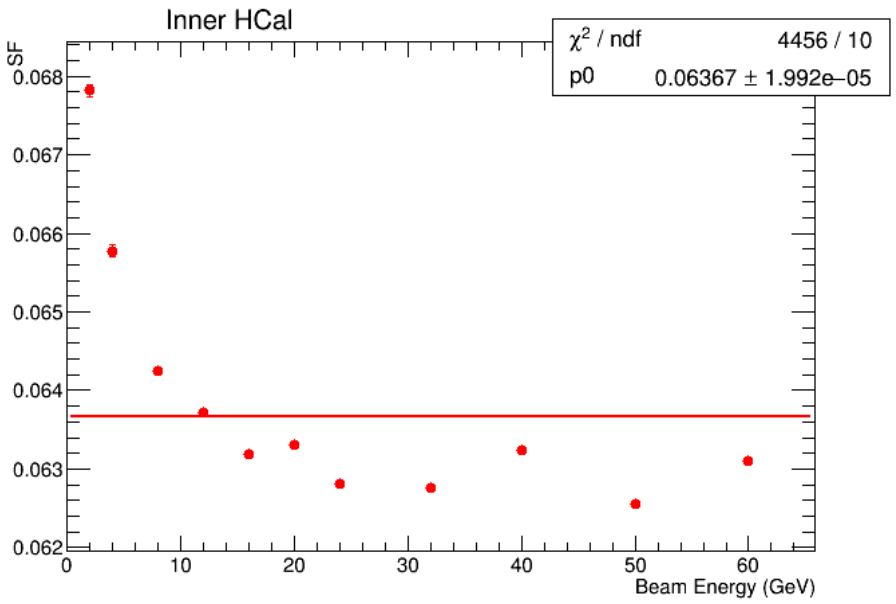
1st Hcal Prototype Results

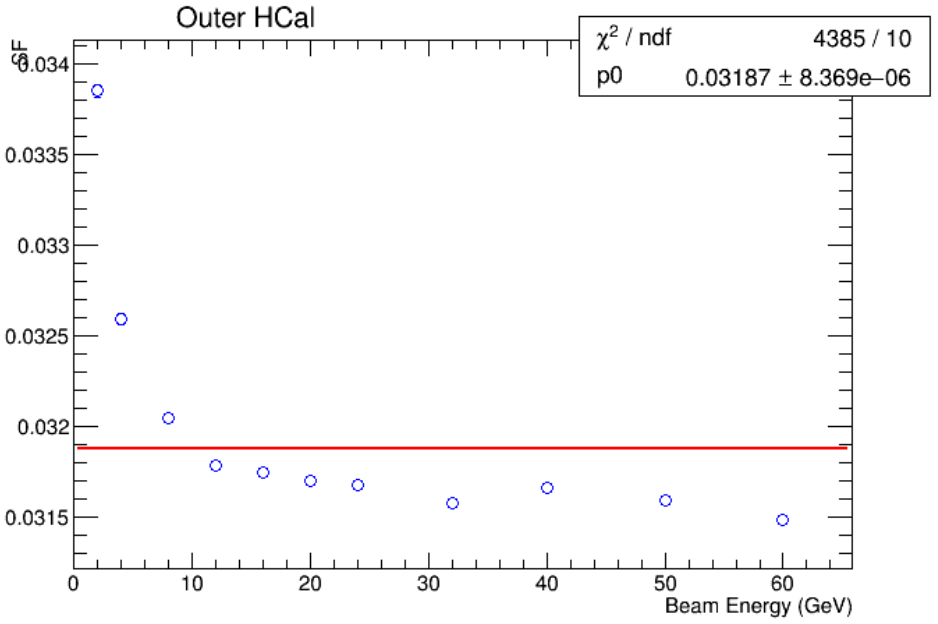




- Energy resolutions from GEANT4 simulation result and test beam measurement are comparable.

HCal Sampling Fractions

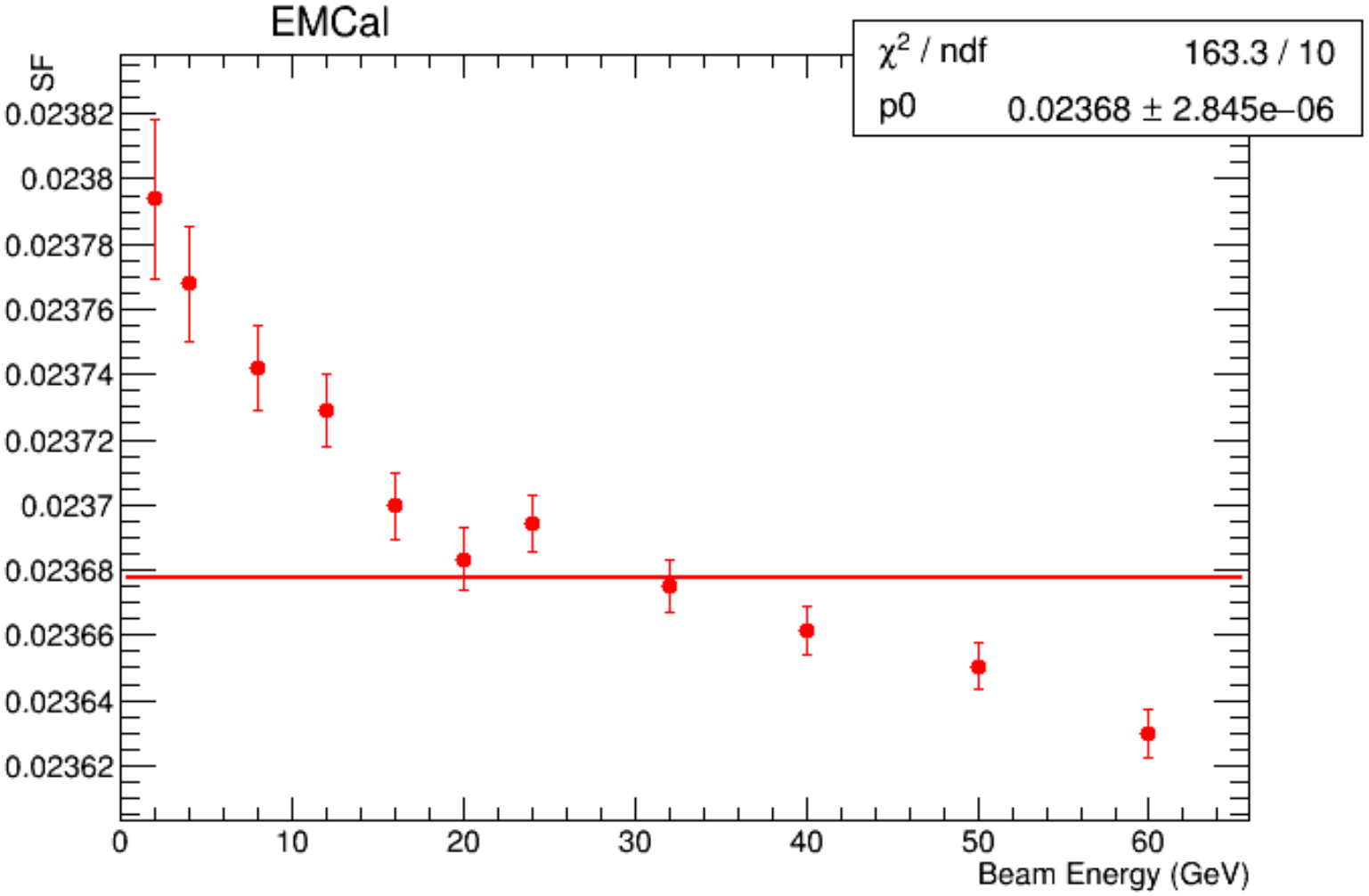




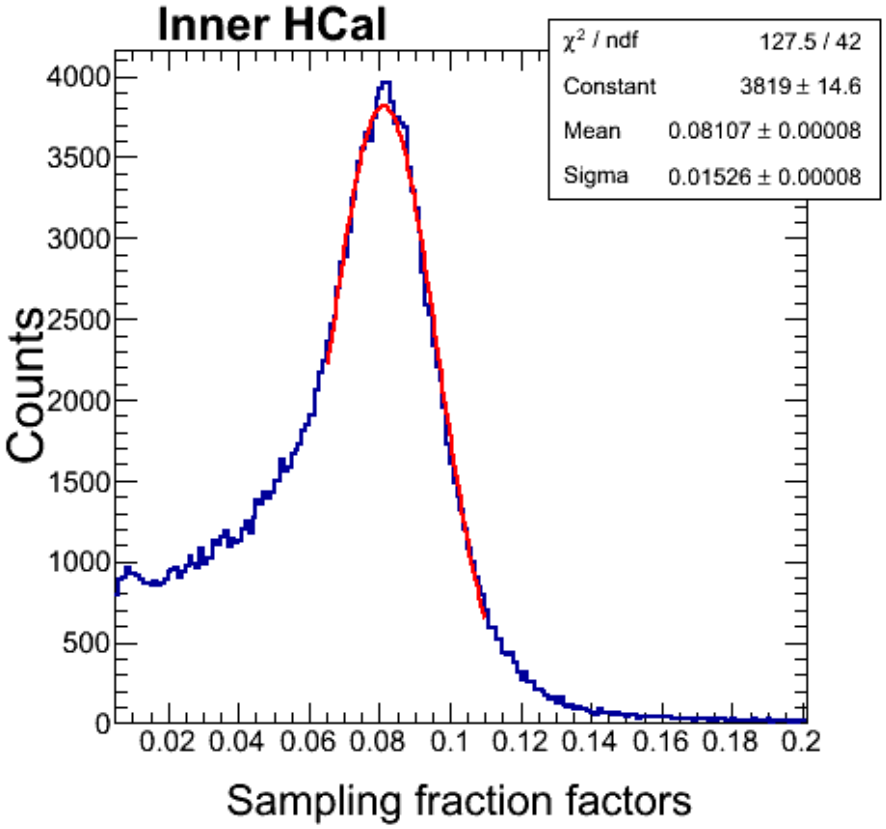
Inner = 6.37%

Outer = 3.19%

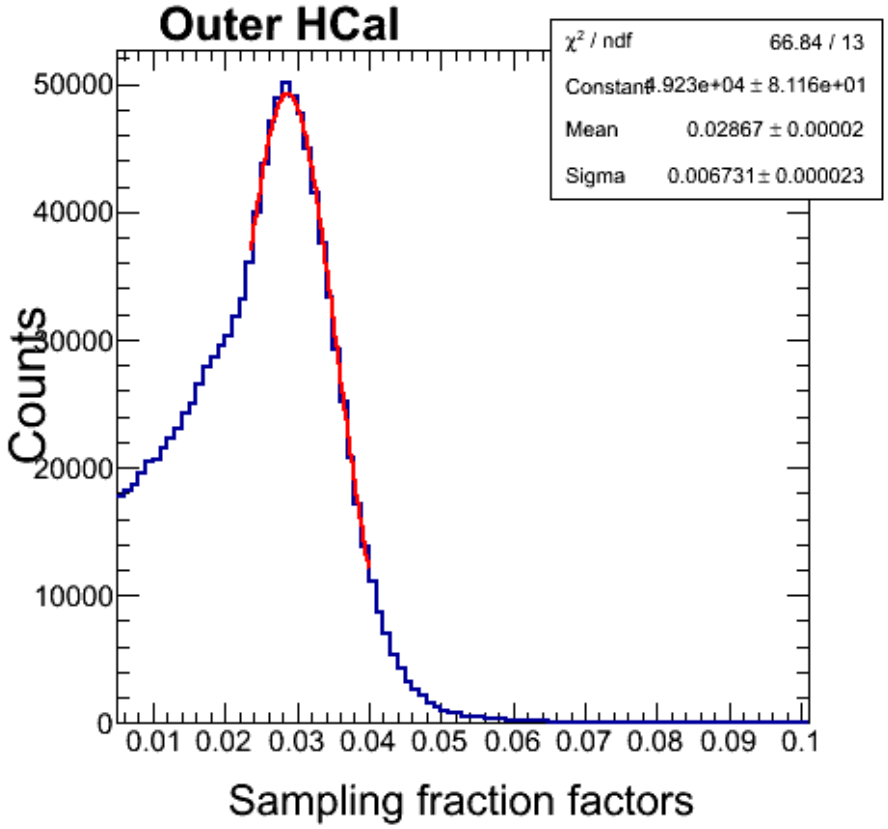
EMCal Sampling Fraction



HCal Sampling Fraction Distributions cosmic $\mu^{\pm}$

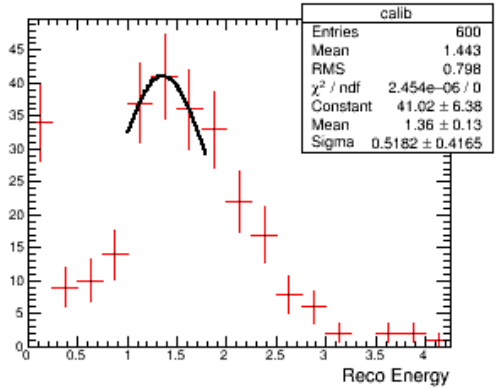


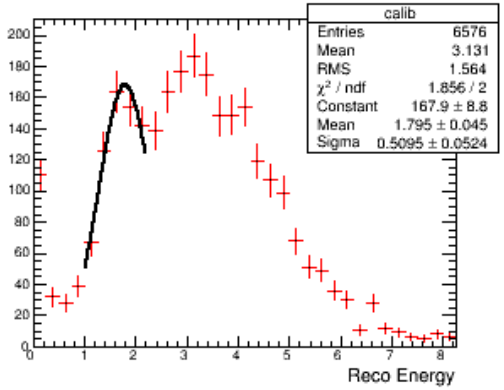
8.11%

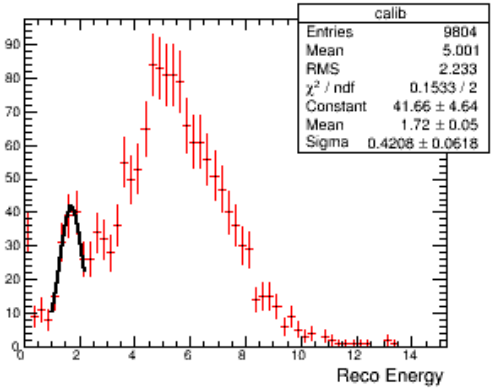


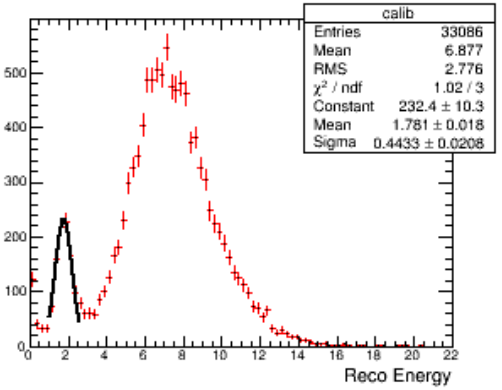
2.87%

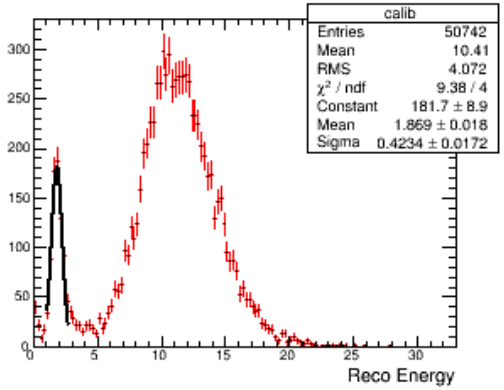
Energy Deposited by Test Beam / Data

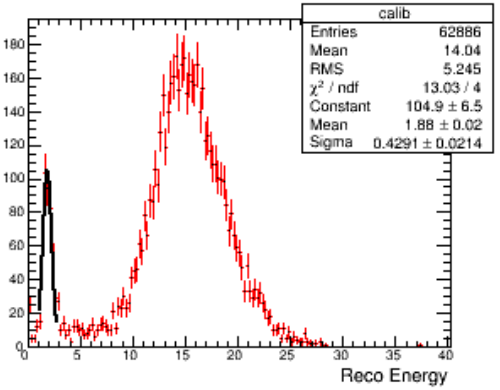


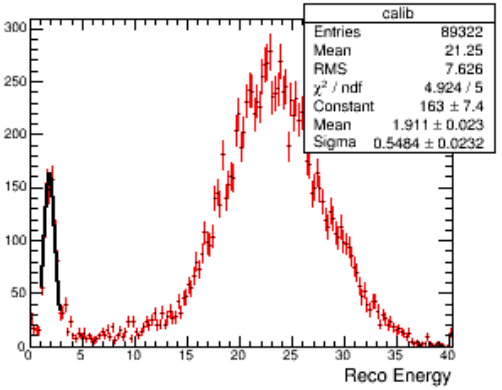


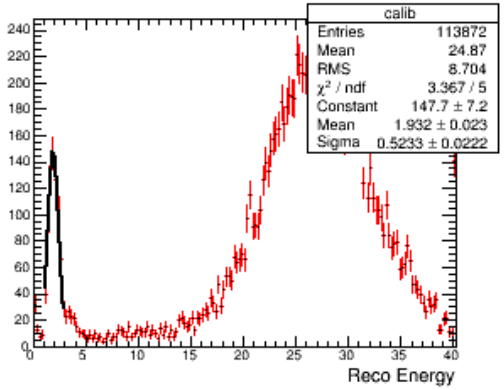






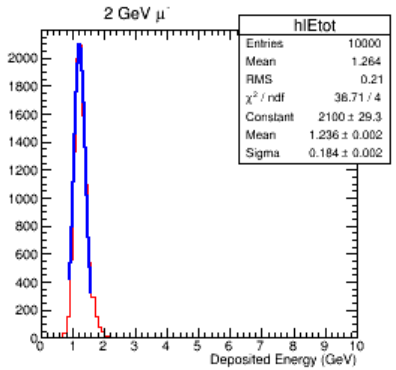


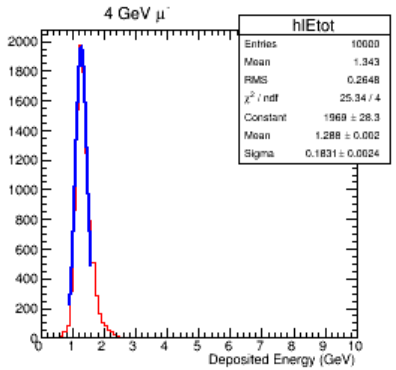


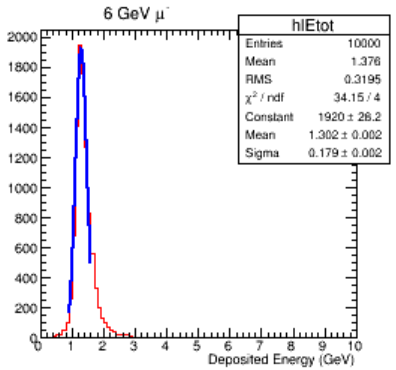


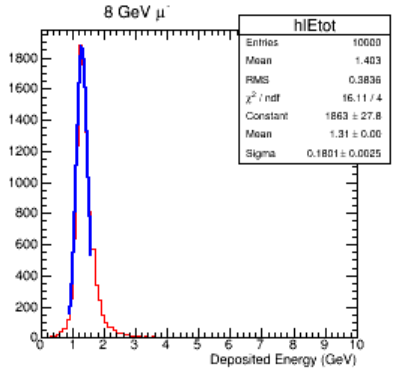
Fitting the muon peak!

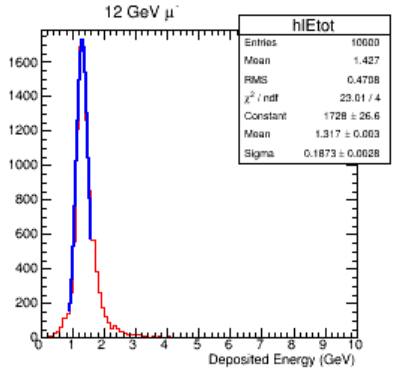
Energy Deposited by Simulated Test Beam/ Muons

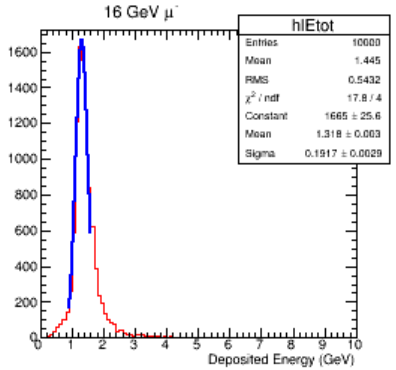


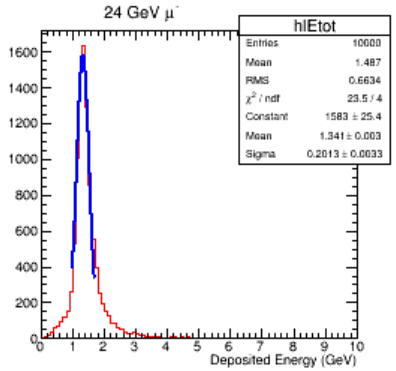


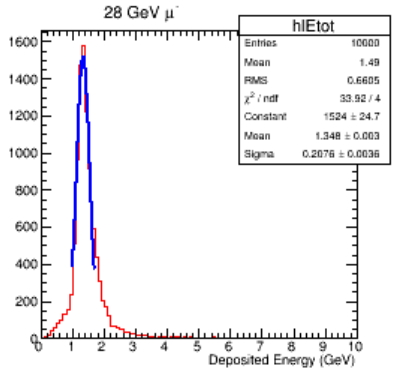




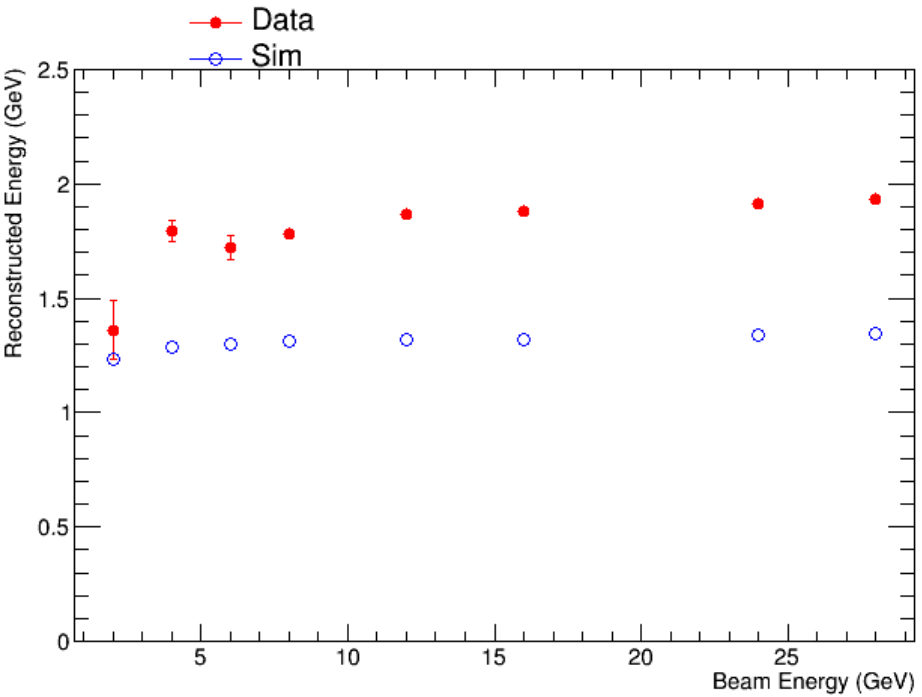


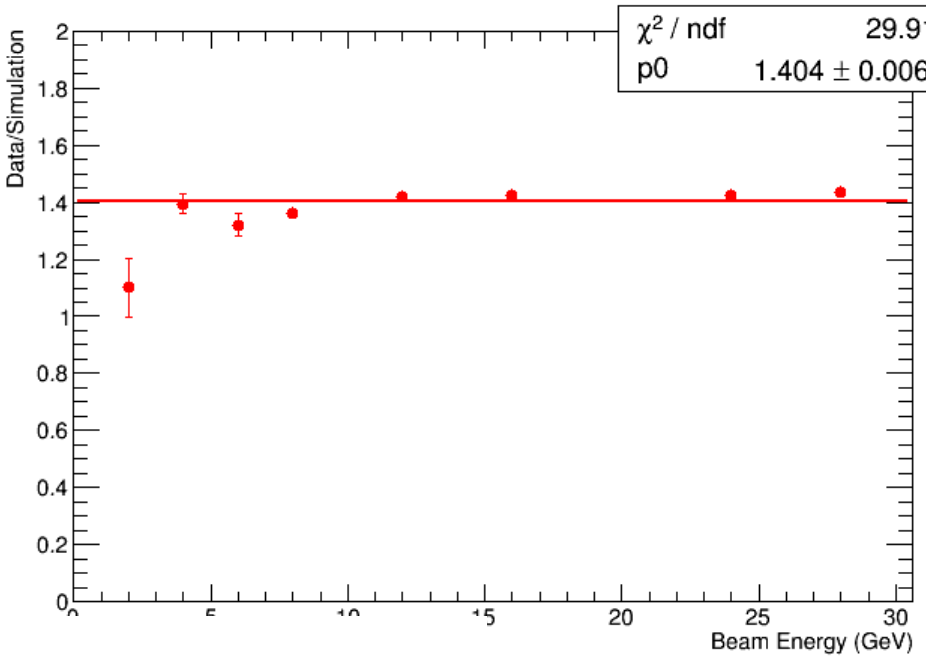


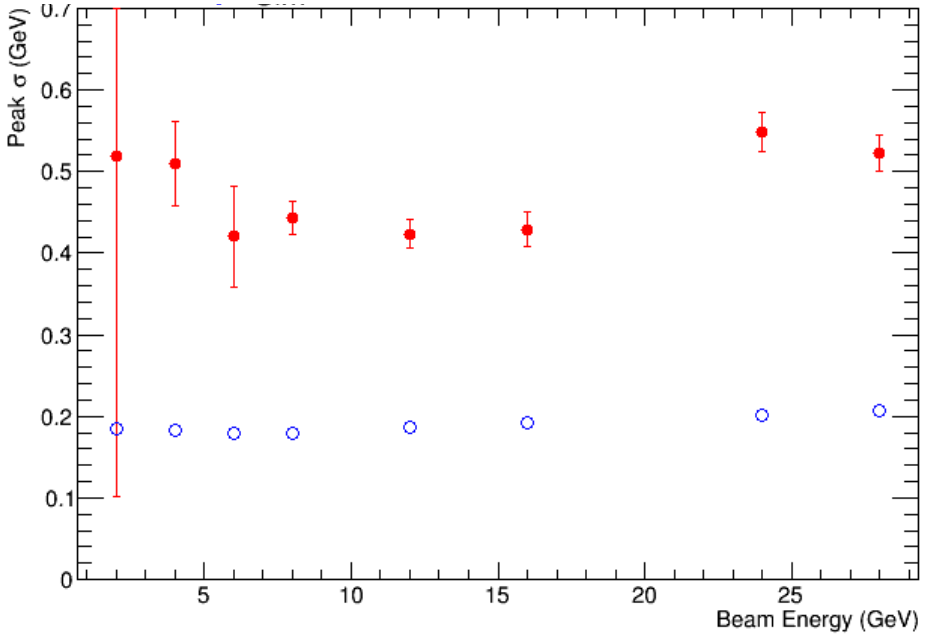




Peak Mean and Width for Data & Simulation







Standalone Detector Display